

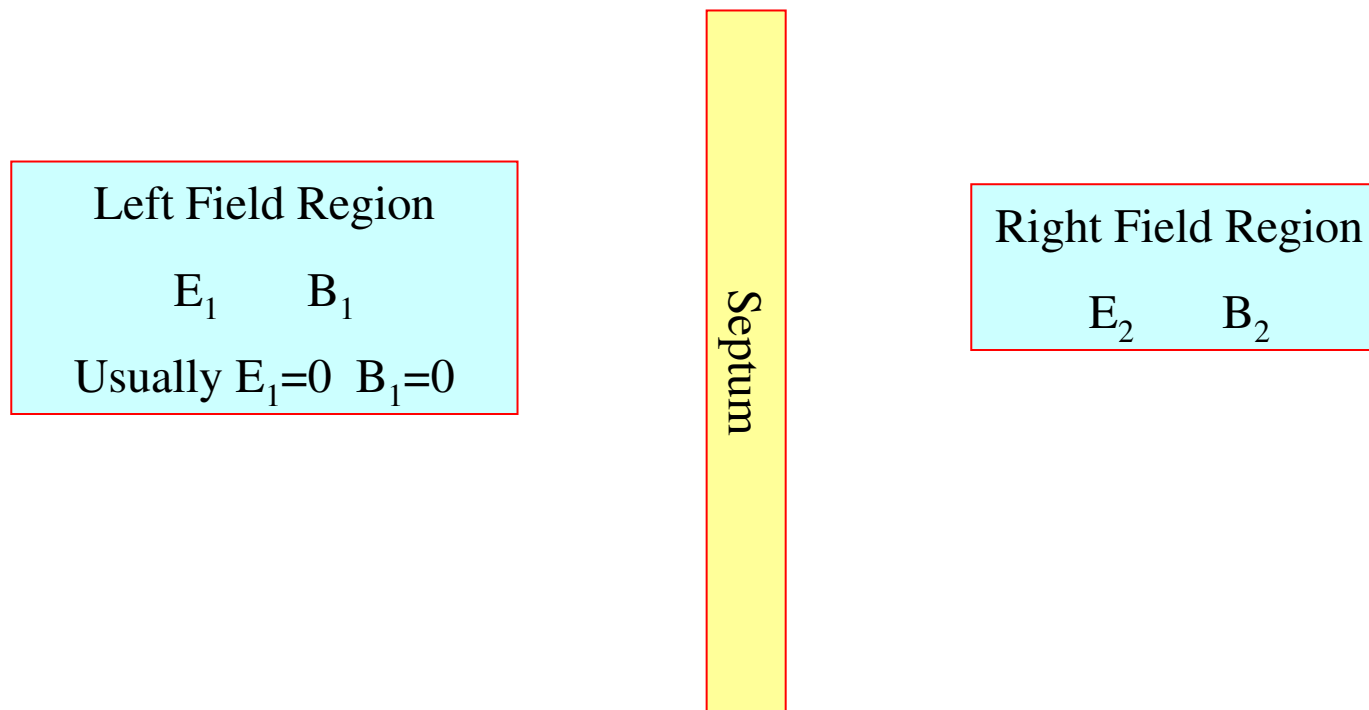
Septa Magnets

Modeling Measuring and Performance

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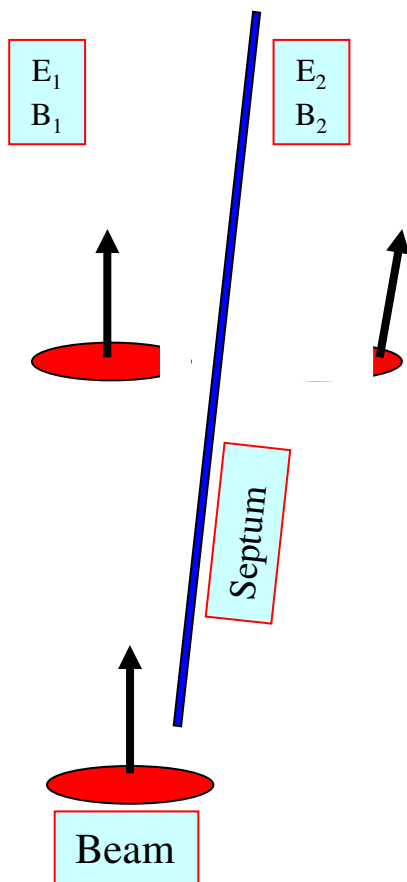
What is a “Septum”?

A “septum” in accelerator and beam_ line physics is a device which separates two field regions

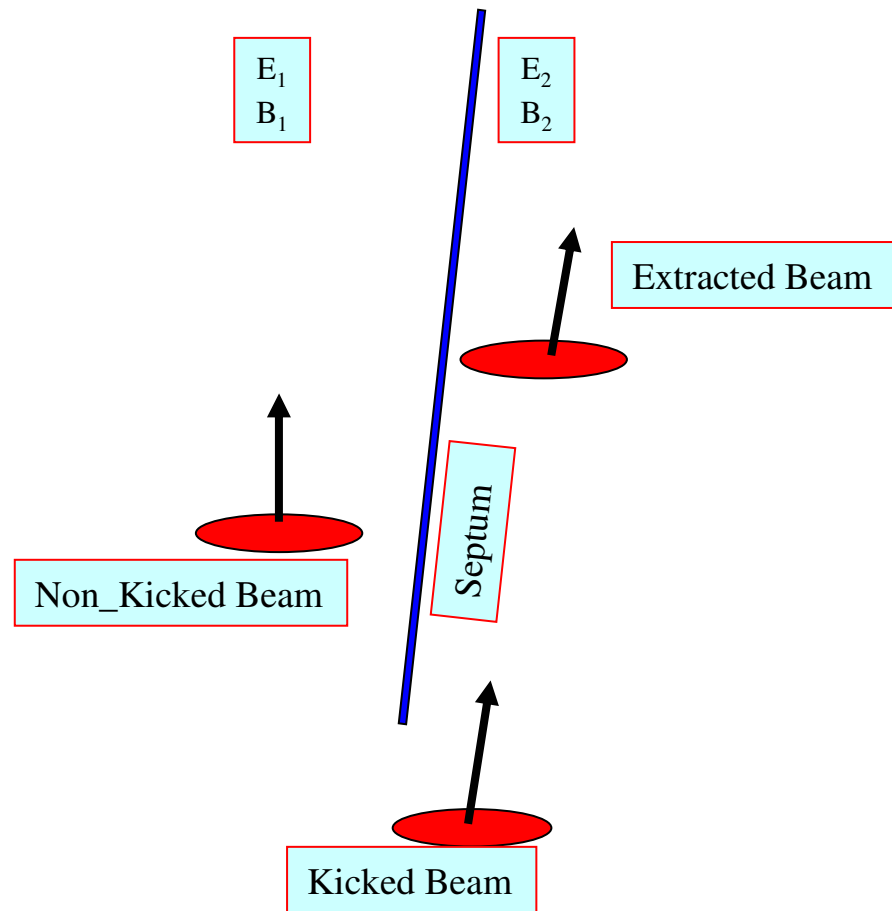


What is the application of a “Septum” in accelerator physics?

To be used as “beam splitter”



To be used as beam “Extractor/Injector” in conjunction with a “kicker” upstrm/downstm



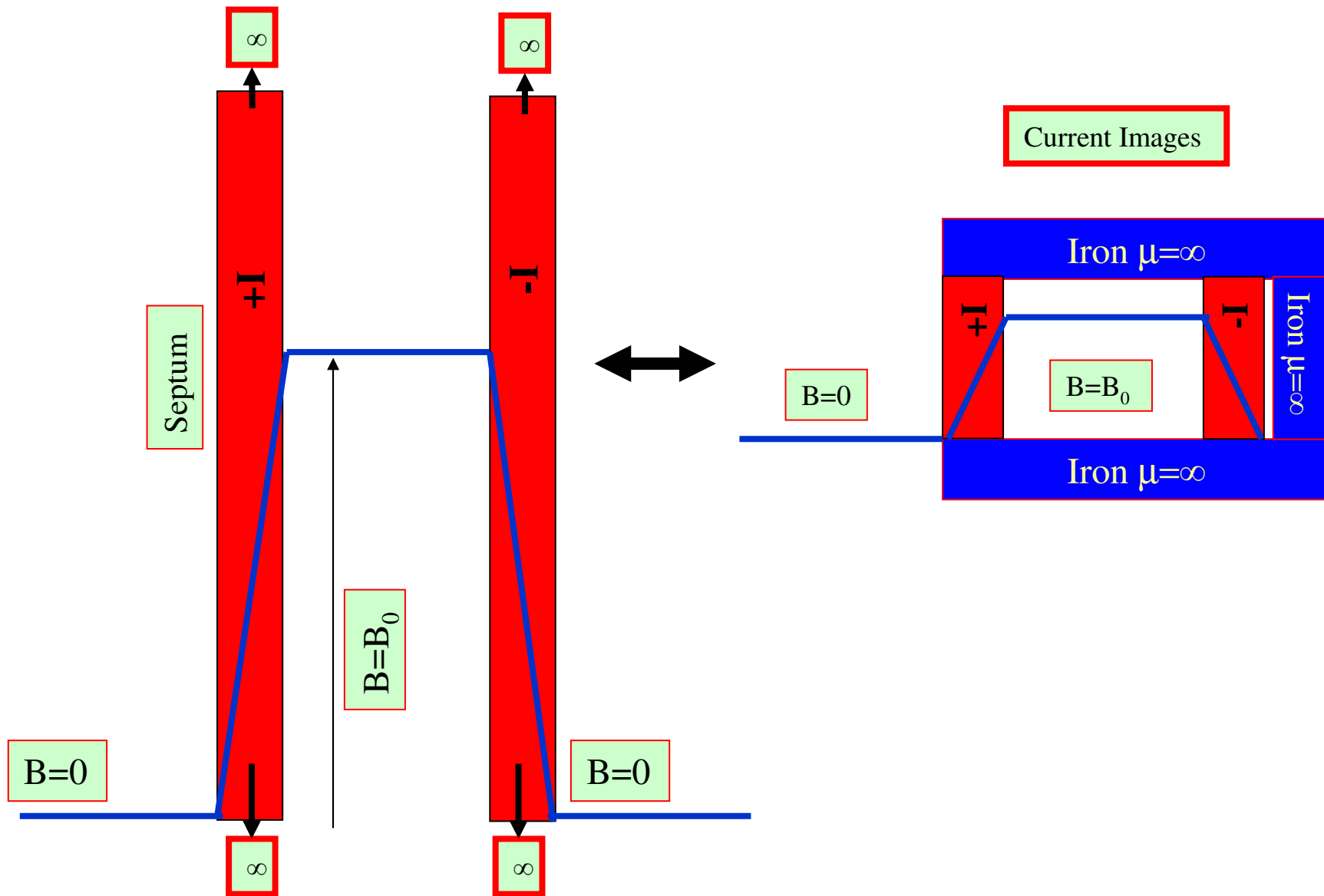
Types of “Septa”

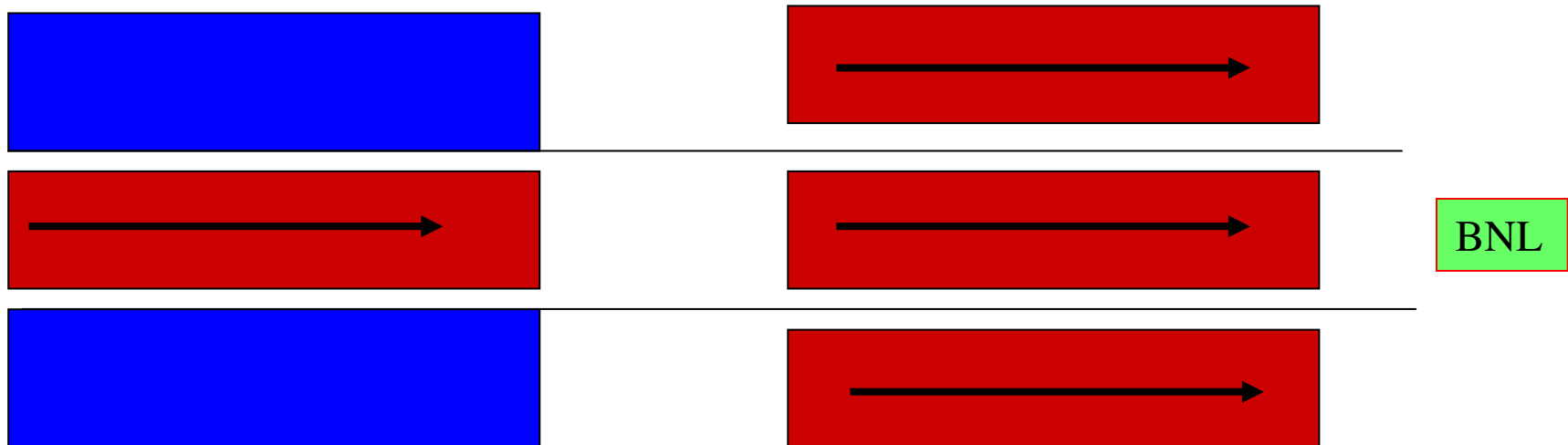
I know of

- Electrostatic Septa (Usually are used as beam_splitters)
- Magnetic Septa:
 - “Current” Septa (Pulsed or DC)
 - “Lambertson” Septa (Usually DC)
- Electro-Magnetic Septa OR “Induction Septa”:

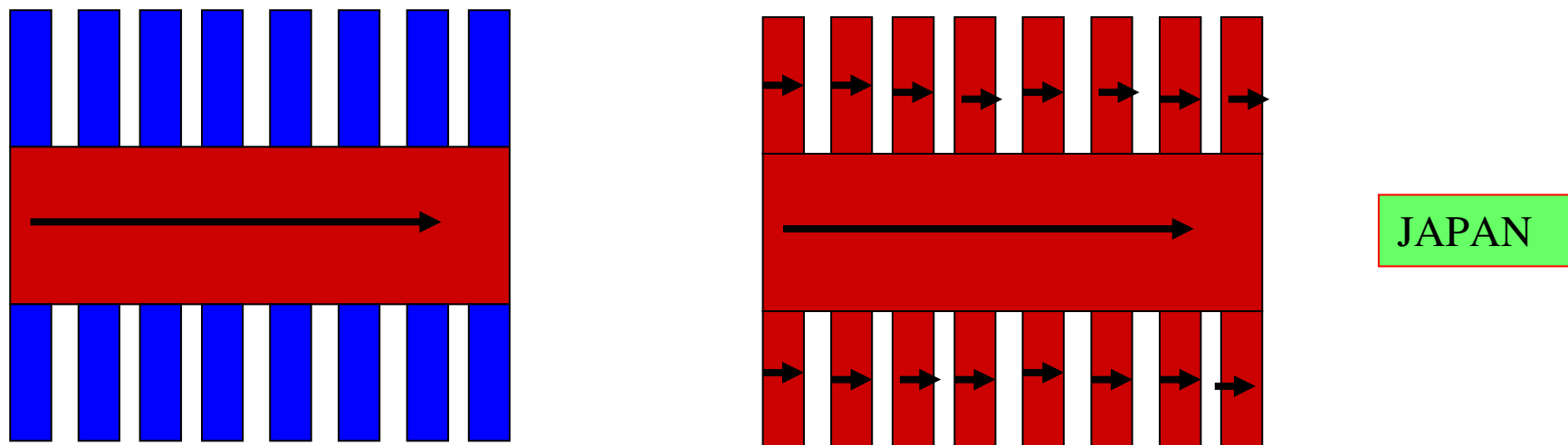
Principle of “Current” Magnetic Septum

Use of current (I) to separate Field Regions



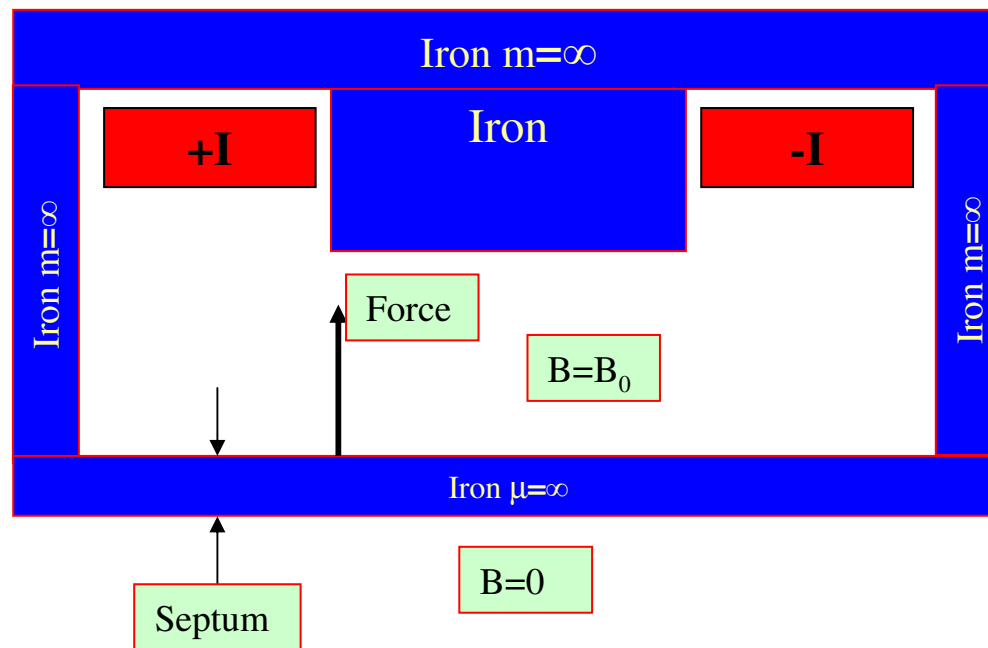


More Image Currents up/down



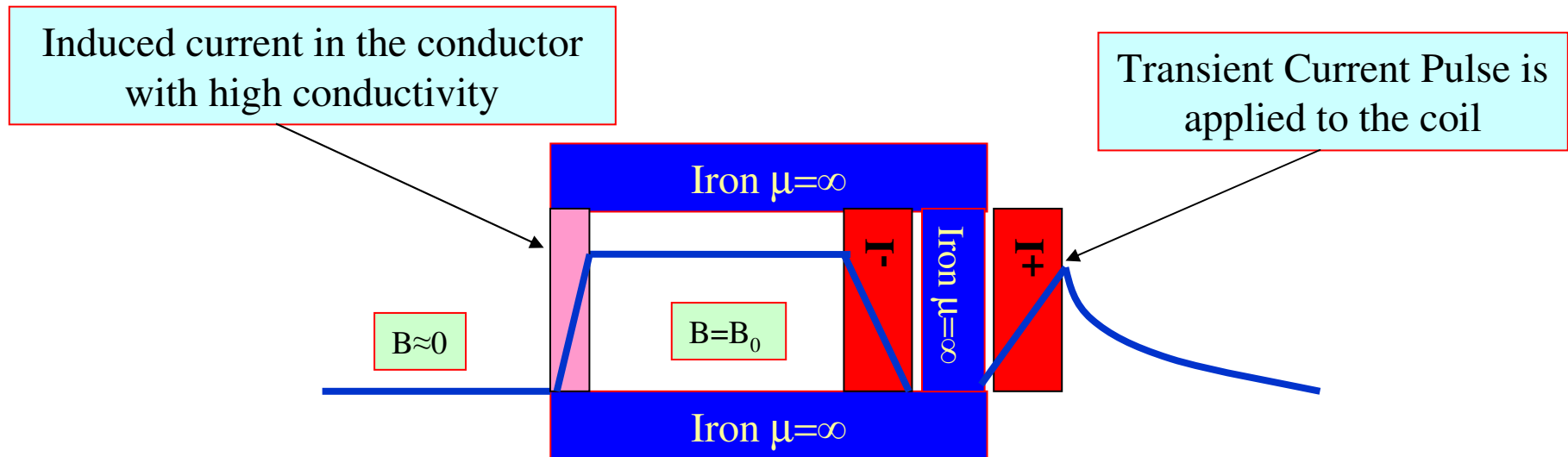
“Lambertson” type Magnetic Septum

Use of magnetic Material to separate Field Regions



“Induction” type Magnetic Septa

Use of High_Conductivity Material to separate Field Regions



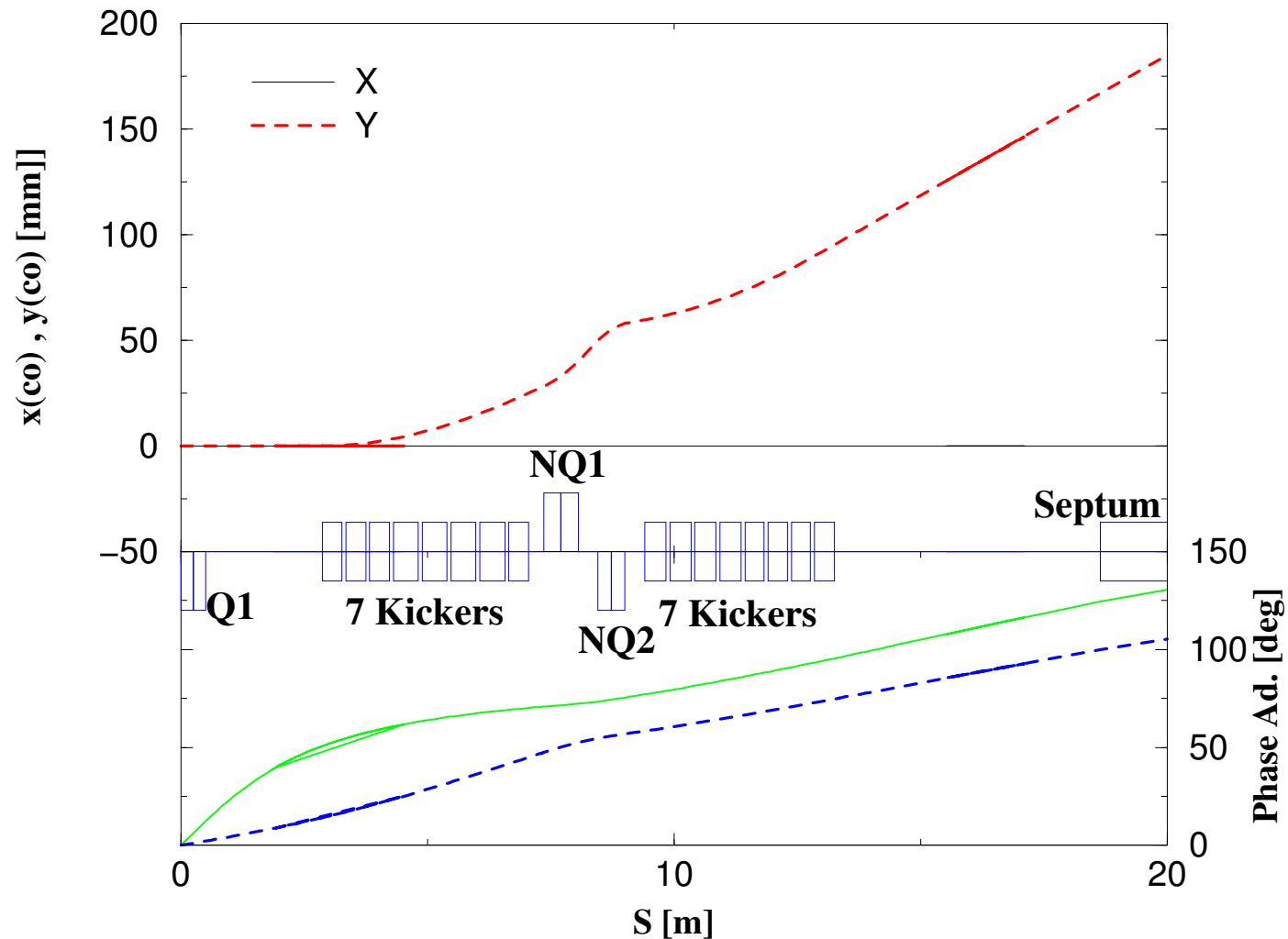
Performed few 2D studies but I did not derive definite conclusions about the advantages over the “regular” septa magnets

Choice of a Septum

- For high intensity beams $>10^{13}$ ions/bunch a “Lambertson type septum” is a better choice because the magnet coil is not exposed directly to the beam.
{ We have been using a “current” septum extracting $\sim 7 \times 10^{13}$ ions/Magnet_Cycle(3 sec)} !!!!
- For a “current” septum, the Kicker and the Septum are both acting on the beam in the same plane. This makes it easy to match dispersion.
{If Dispersion Beam_Matching is of importance}
- For a “Lambertson” septum:
 - Kicker kicks in the Vertical plane. Therefore small vertical dispersion may be introduced to the beam. This dispersion can be corrected with additional magnets.
 - The non-median plane symmetry introduces “skew” multipoles.
 - A small beam coupling is also introduced due to the horizontal bend while the beam is traveling vertically.
- If the Septum runs at high fields, one has to consider and study the consequences of the magnetic field saturation for the choice of septum
- The minimum Septum thickness depends:
 - On the rate of the heat removal from the septum (“current septa”) to keep the conductor at safe temp.
 - The effect of the iron_saturation on the region of the circulating beam (“Lamb. septa”)
- Injection/Extraction Septa work in conjunction with kickers :
 - Beam Optics in conjunction with magnet design will help define the optimum location and strength of the kicker(s) and septum magnet.
 - The energy of the circulating beam and the possible modes of operation of the accelerator introduces additional constraints on the septum design.

Beam optics calculations were performed to optimize the location and strength of the kickers and Extraction septum of the SNS ring

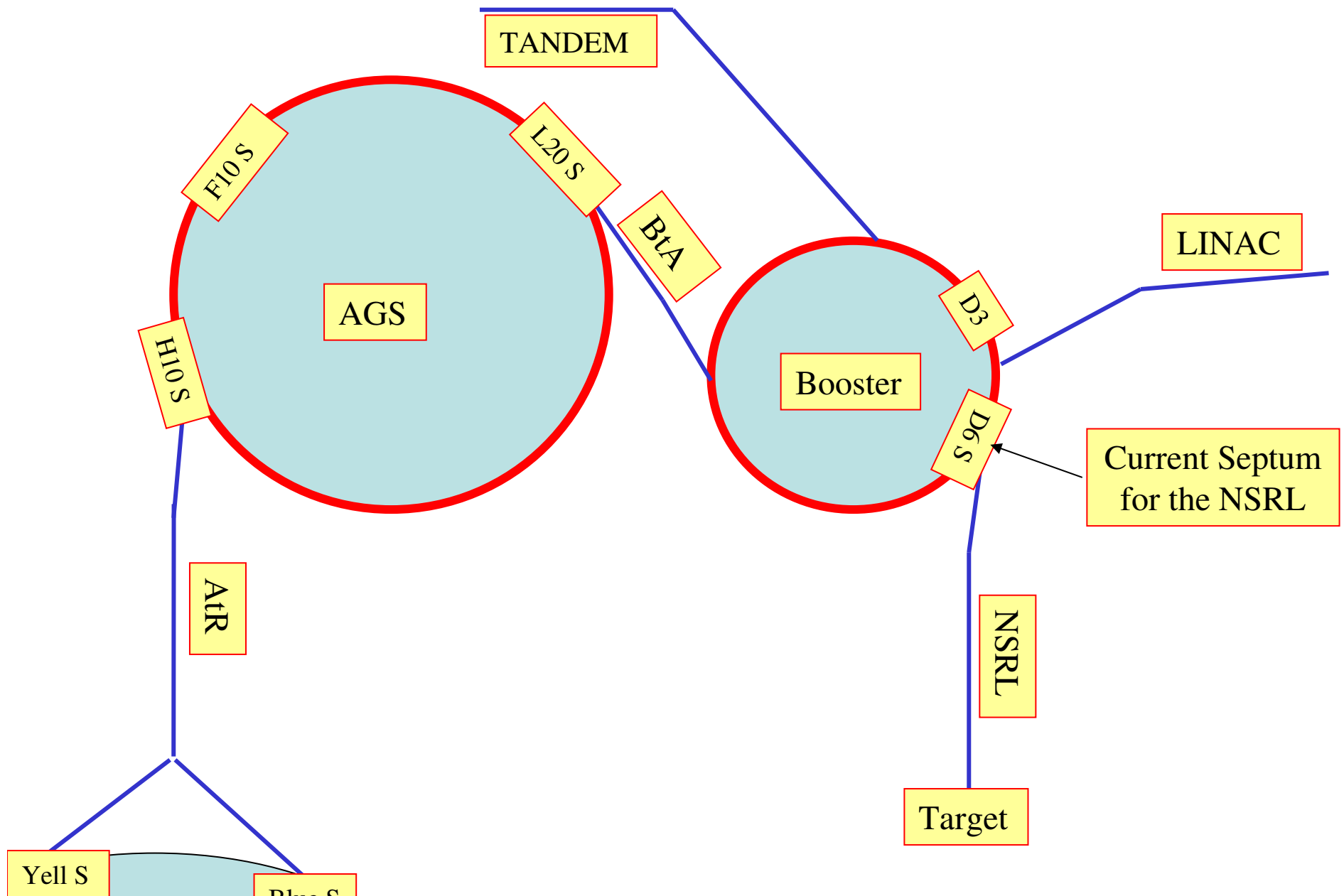
Y_{cod} vs Dist. during beam Extraction



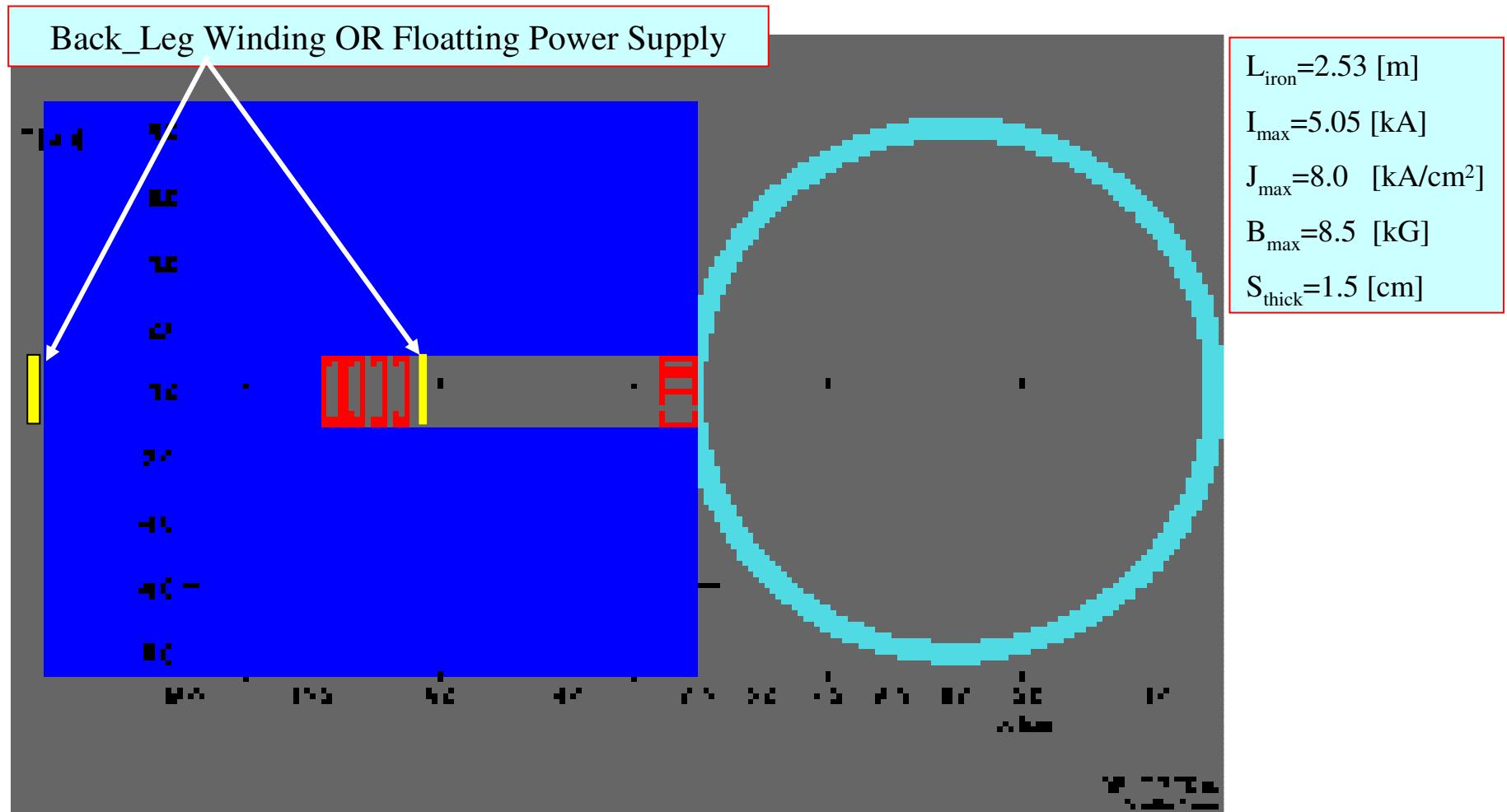
Modeling a Septum Magnet

- “Current” Septum:
 - Two Dimensional Modeling of a current Septum ($\text{gap} \ll \text{Length}$) is rather sufficient.
 - In the septum region choose a conductor size which satisfies the cooling requirements.
 - In the model of the magnet use a large enough **grid_size_density** which make the results from the solution of the model independent of the grid size.
 - Methods used in minimizing the field in the “zero_field” region
 - Implementation of a Back_leg winding
 - Use vacuum pipe of magnetic material in the “zero field” region.
- “Lambertson” type Septum:
 - Three dimensional modeling of a “Lambertson” septum is a **MUST**:
 - Methods used in minimizing the field in the “zero_field” region
 - Implementation of a magnetic vacuum pipe for the circulating beam.
 - Use of field clamps at the entrance and exit of the circulating beam region.

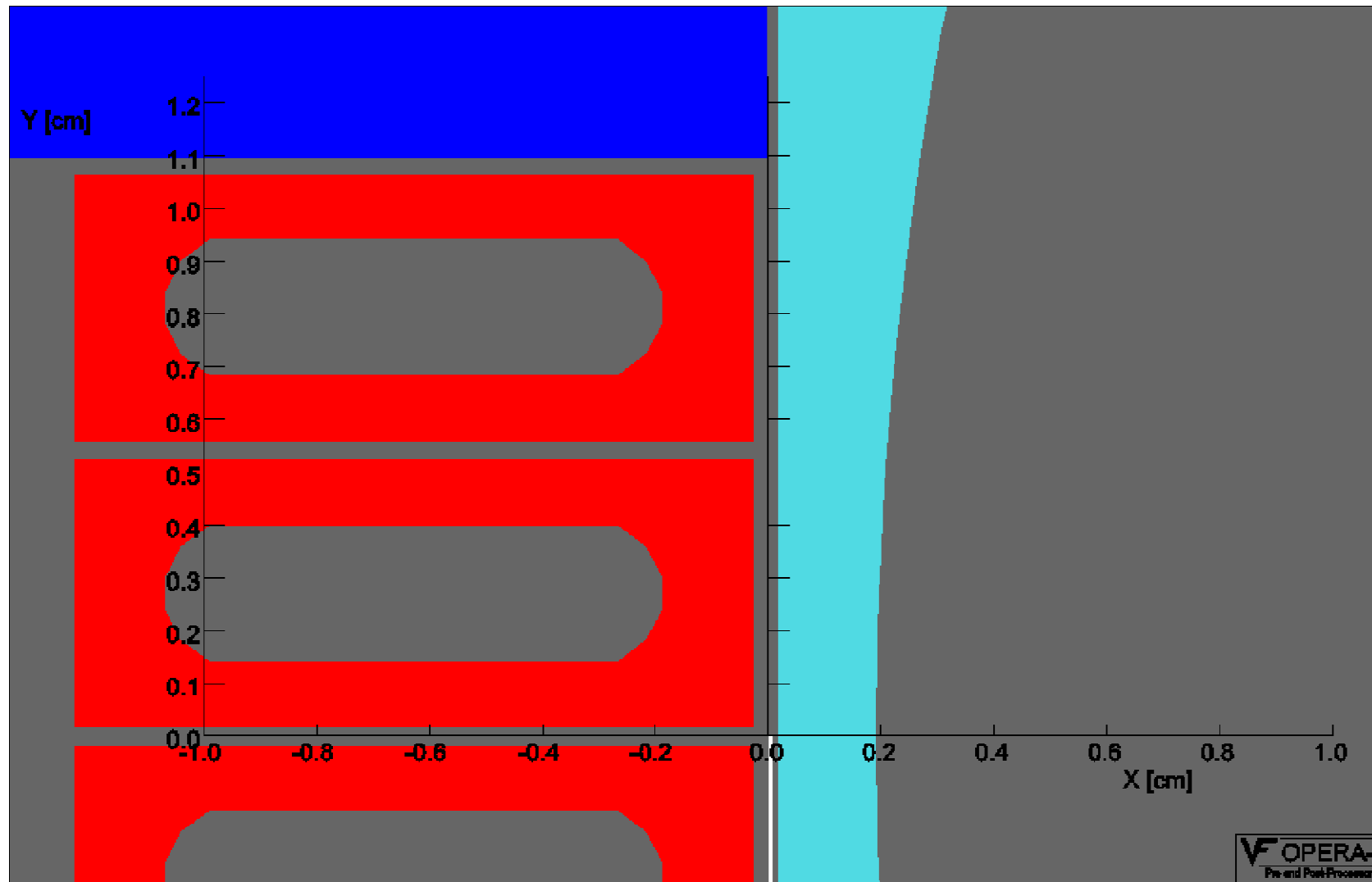
Schematic Diagram of the Booster and AGS Rings with few of the Septa



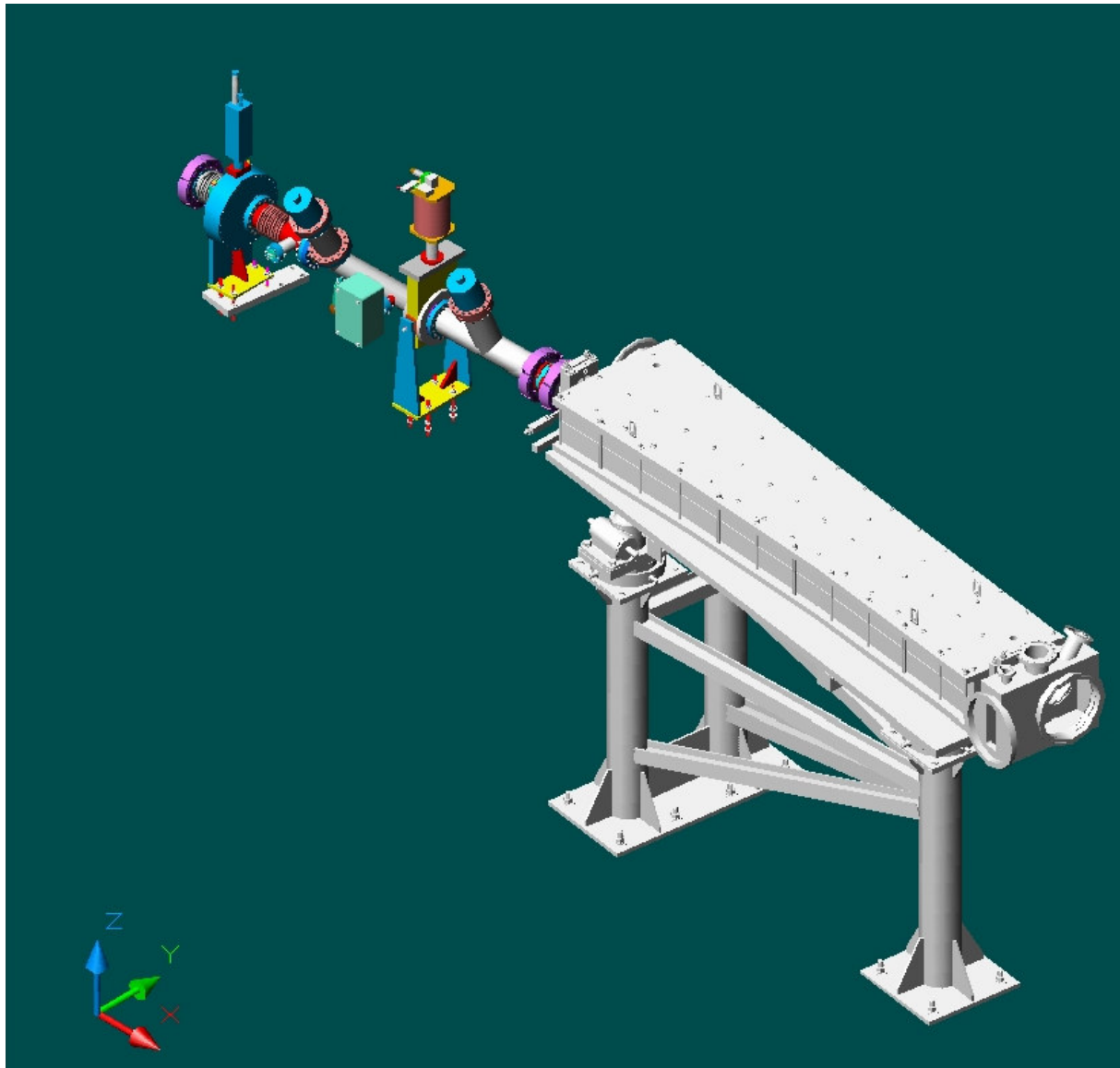
Example of Modeling the “current” Septum Magnet of the
NASA_Space_Radiation_Laboratory (NSRL) Line



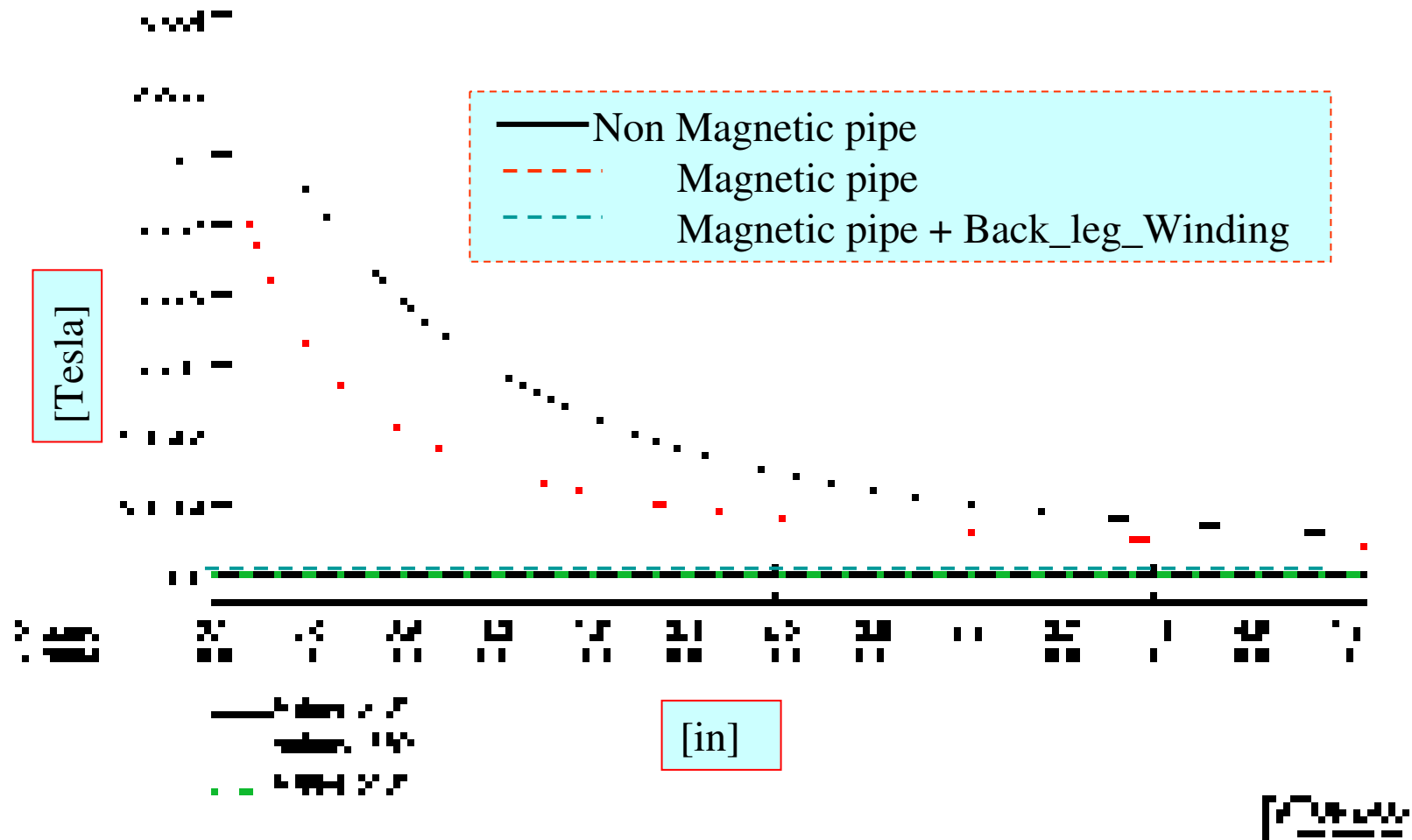
Cross Section of the Septum region of the (NSRL) “current” Septum magnet



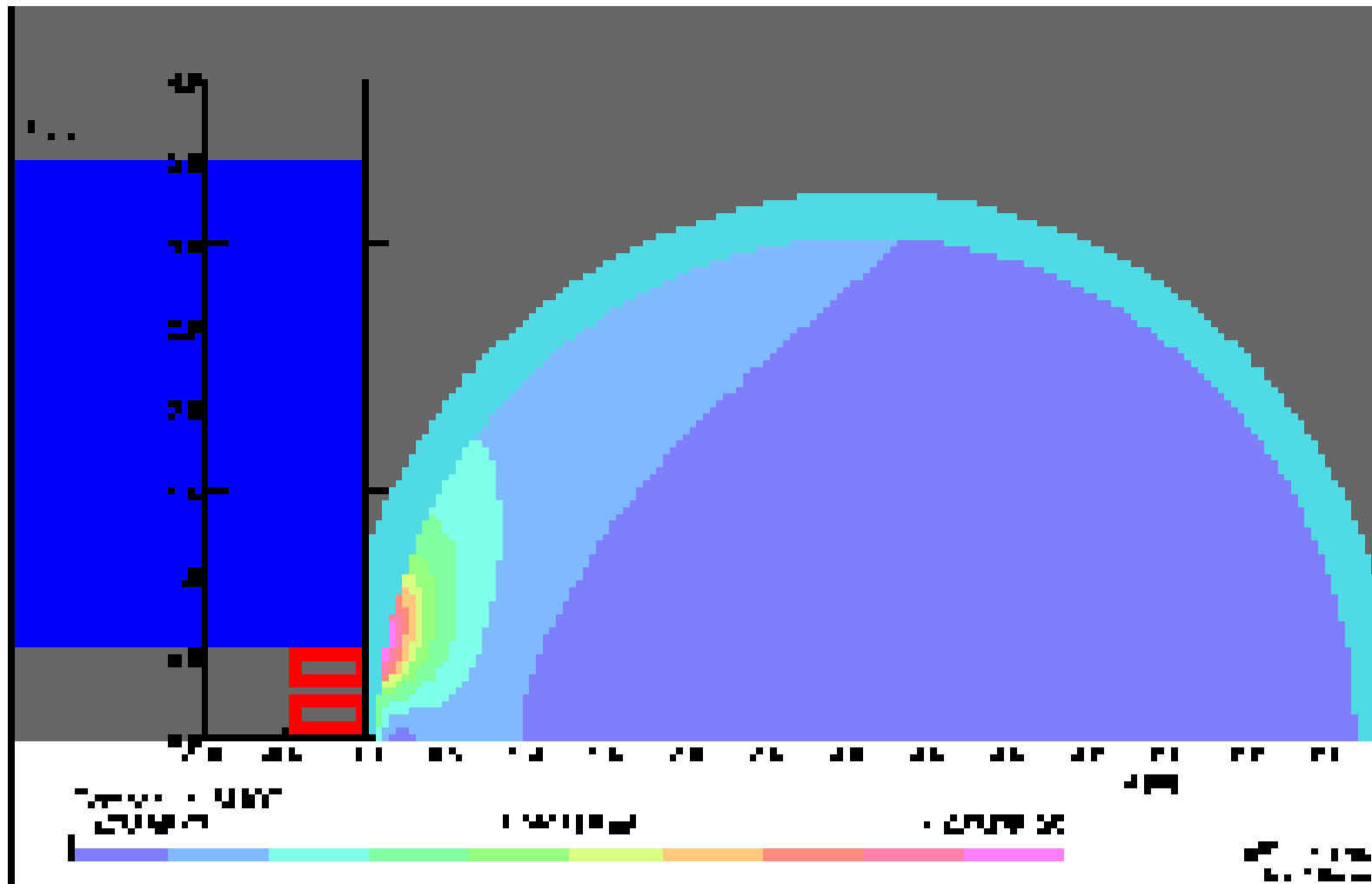
Isometric view of the (NSRL) Line “current” Septum magnet
Engineering Design: **James Cullen, Louis Snyderstrup**



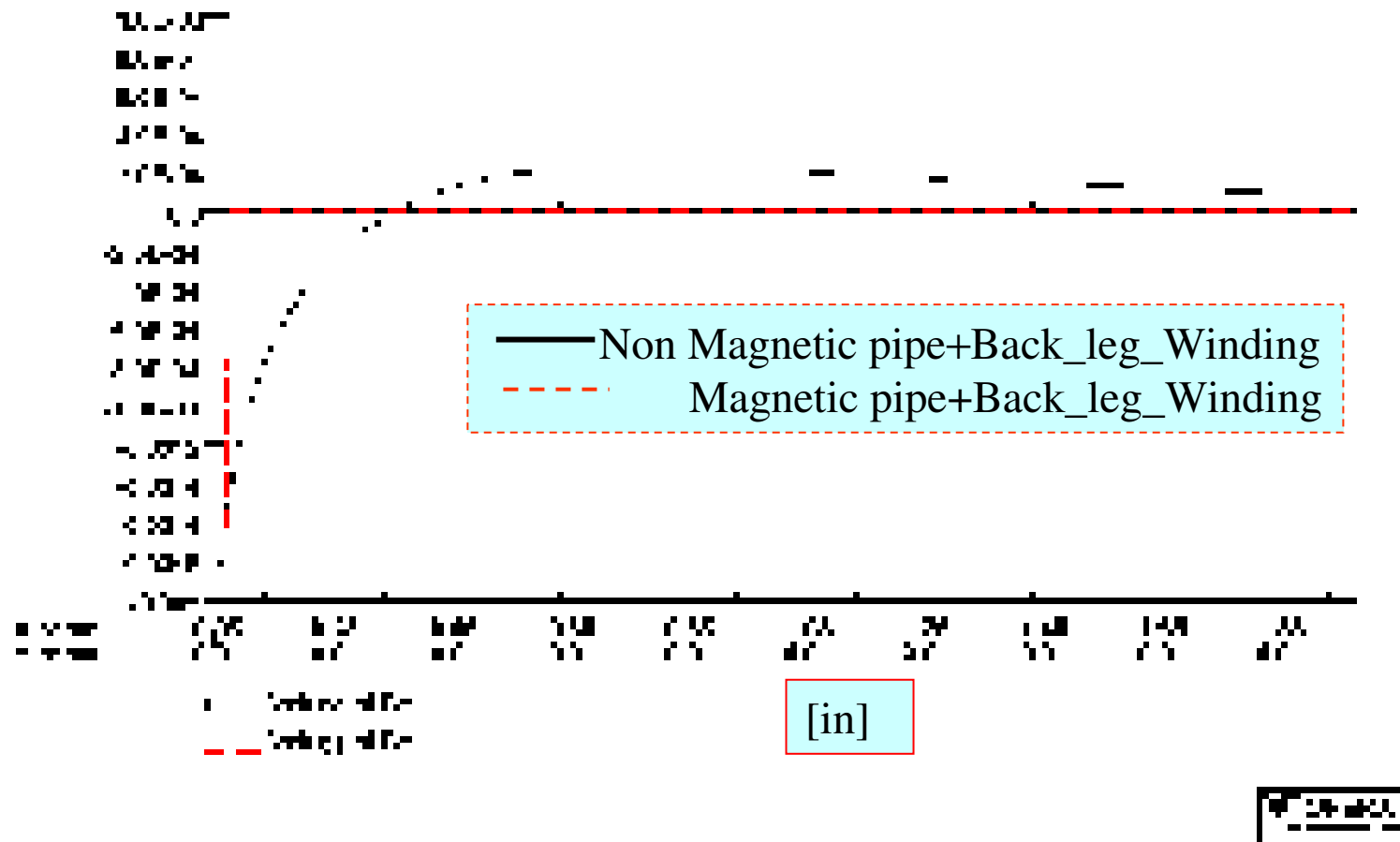
Field strength in the “zero_field” region of the (NSRL) “current” Septum magnet
Magnet Powered at full Strength



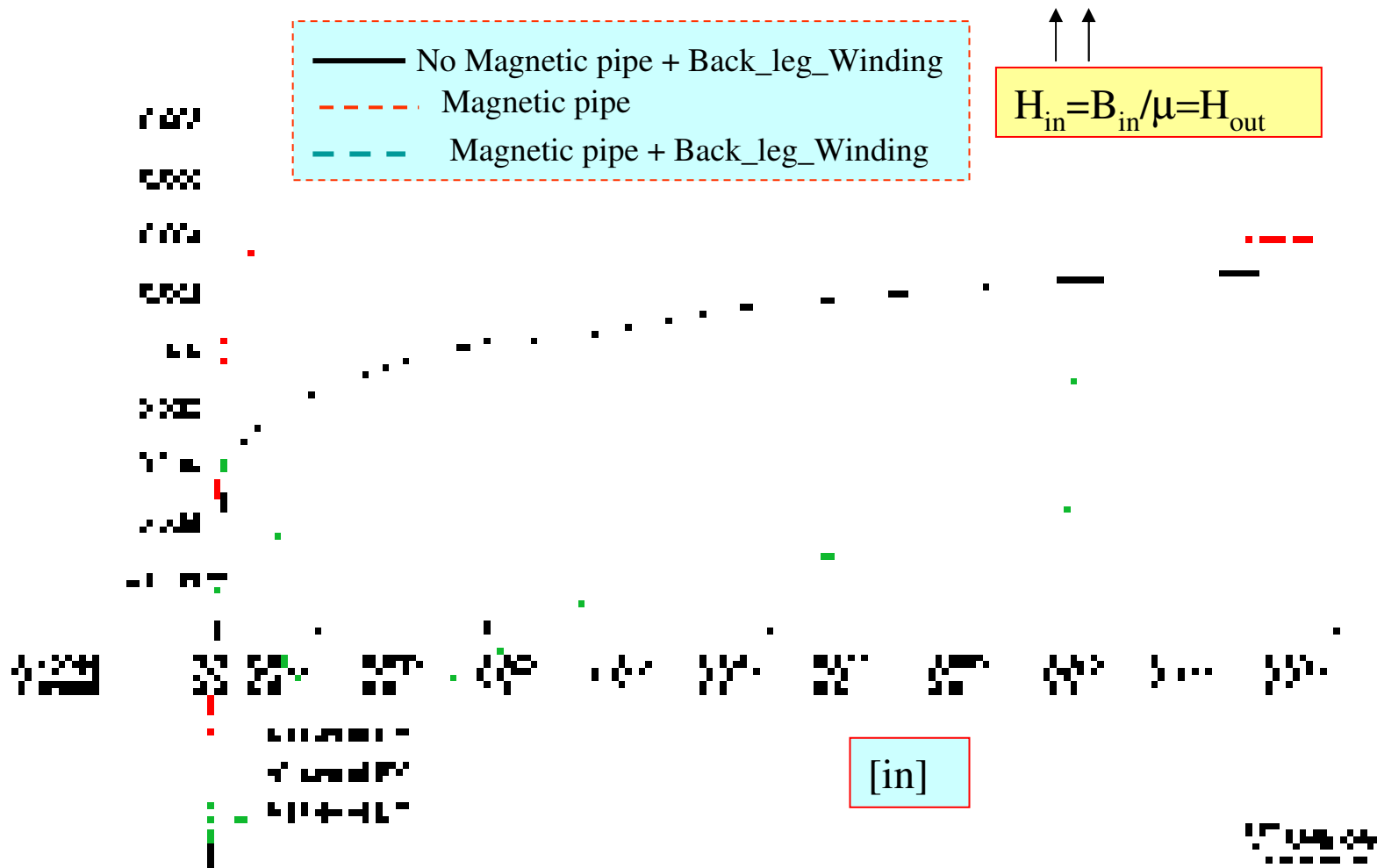
Strength of B_{mod} in the “zero_field” region of the (NSRL) Line “current” Septum magnet
Magnetic Pipe and Back_leg_Winding are being used
Magnet is powered for maximum Field



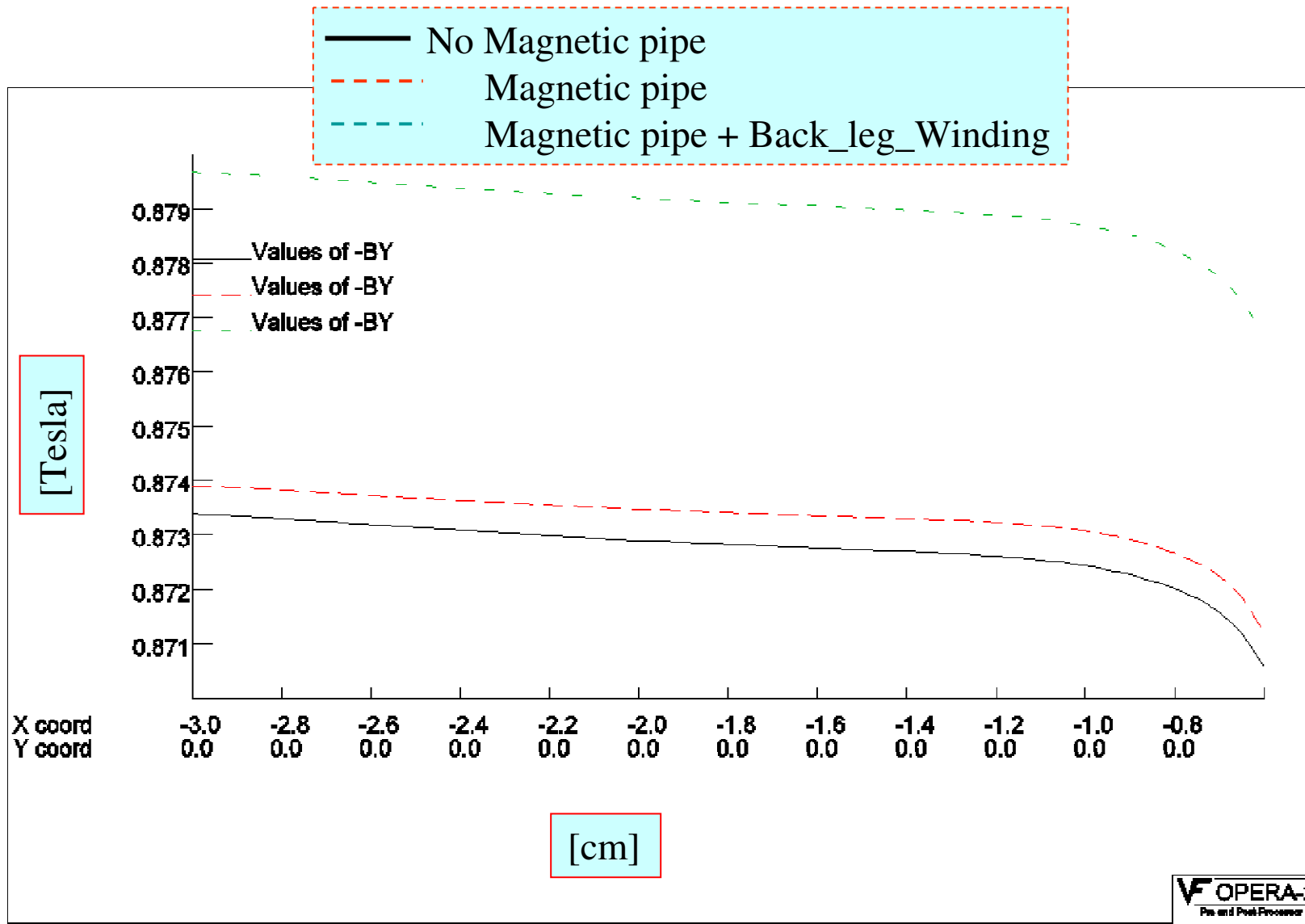
Strength of B_y in the “zero_field” region of the (NSRL) Line “current” Septum magnet
 Magnetic Pipe and Back_leg_Winding
 and with Back_leg_winding only



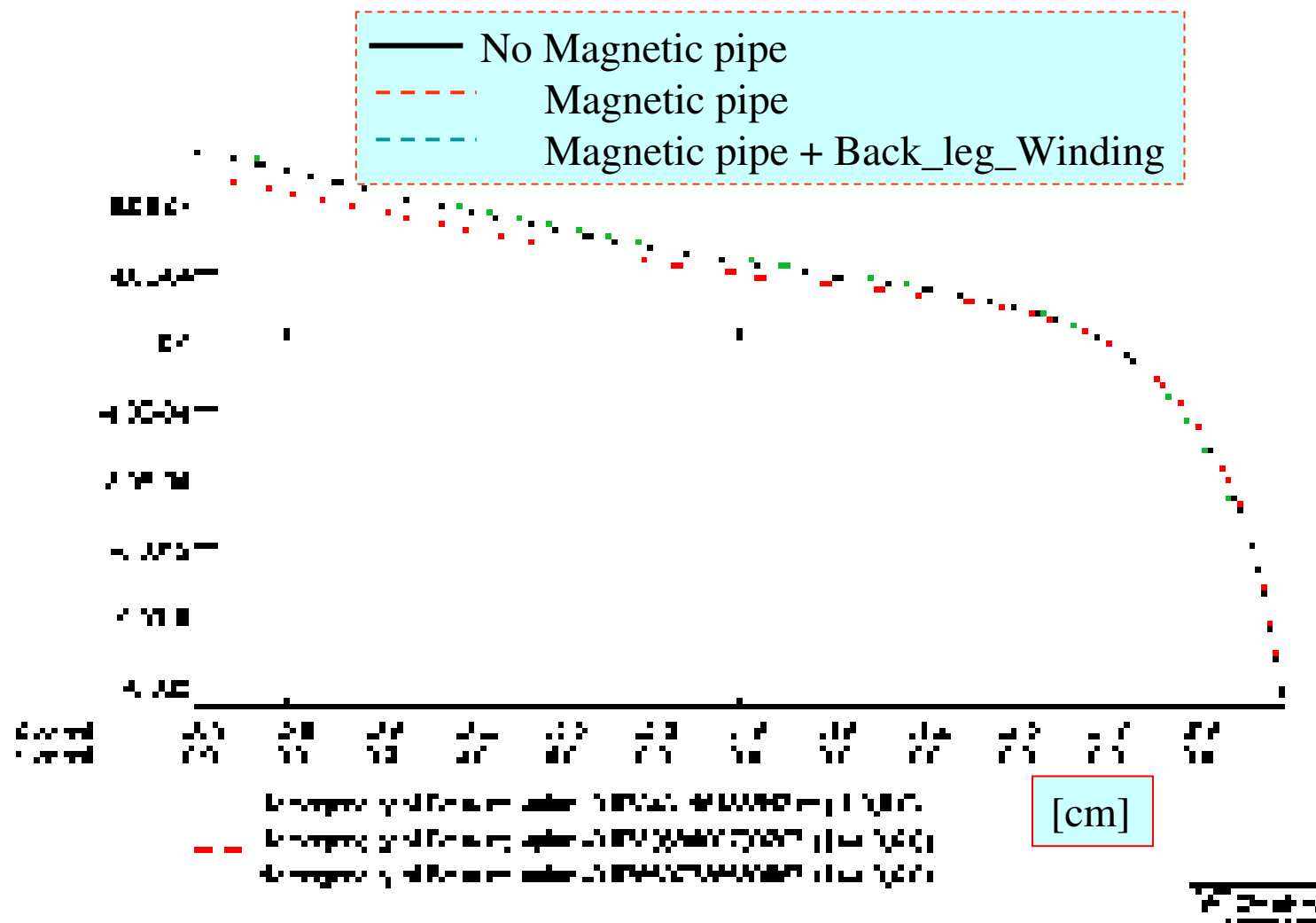
Field_homogeneity in the “Extraction_field” region of the (NSRL)“current” Septum magnet



B_y strength in the “Extraction_field” region of the (NSRL) Line “current” Septum magnet

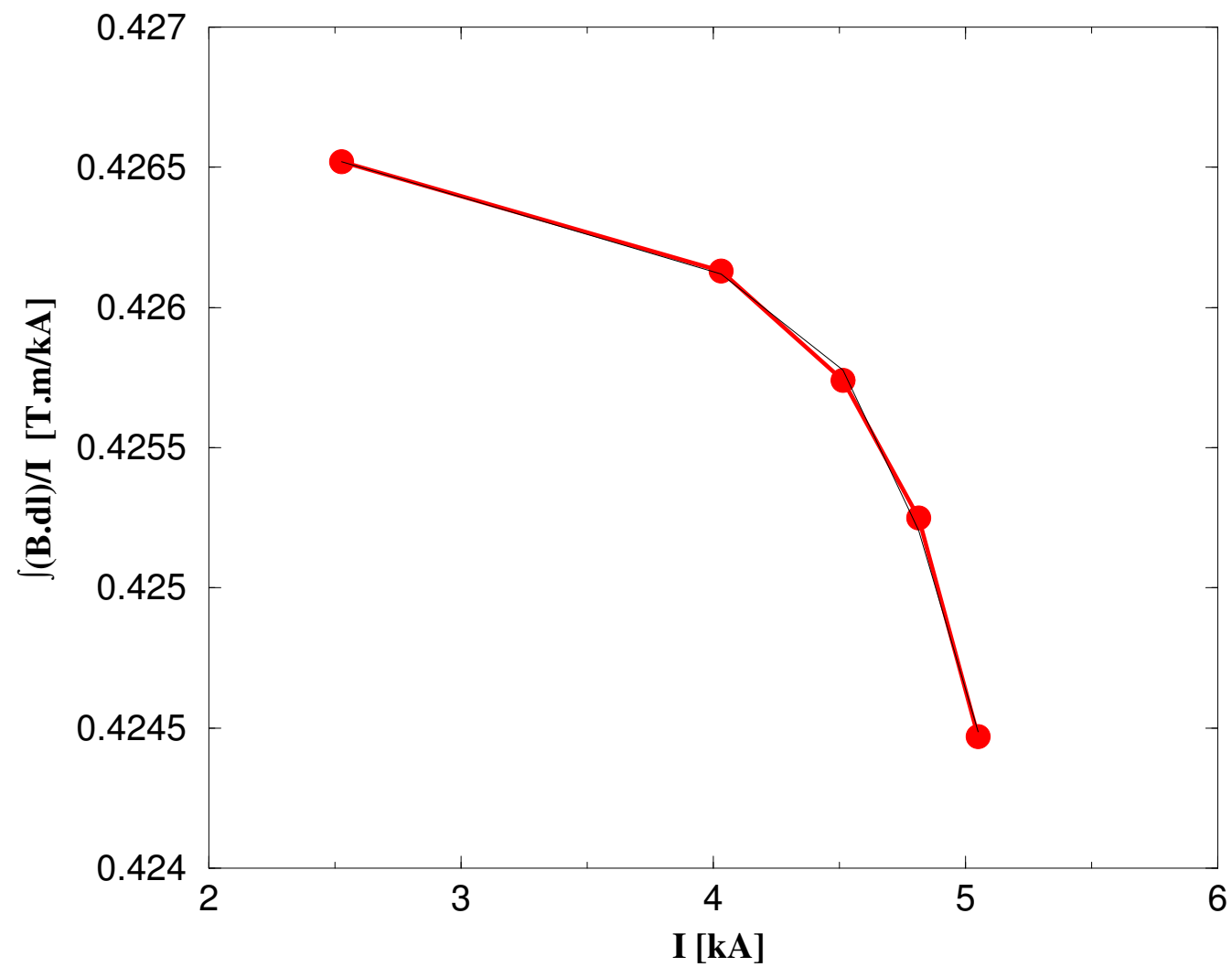


Field_homogeneity in the “Extraction_field” region of the (NSRL)“current” Septum magnet



Transfer Function of D6 Septum

Long Coil Measurements



Experience with the NSRL “D6” “current Septum Magnet

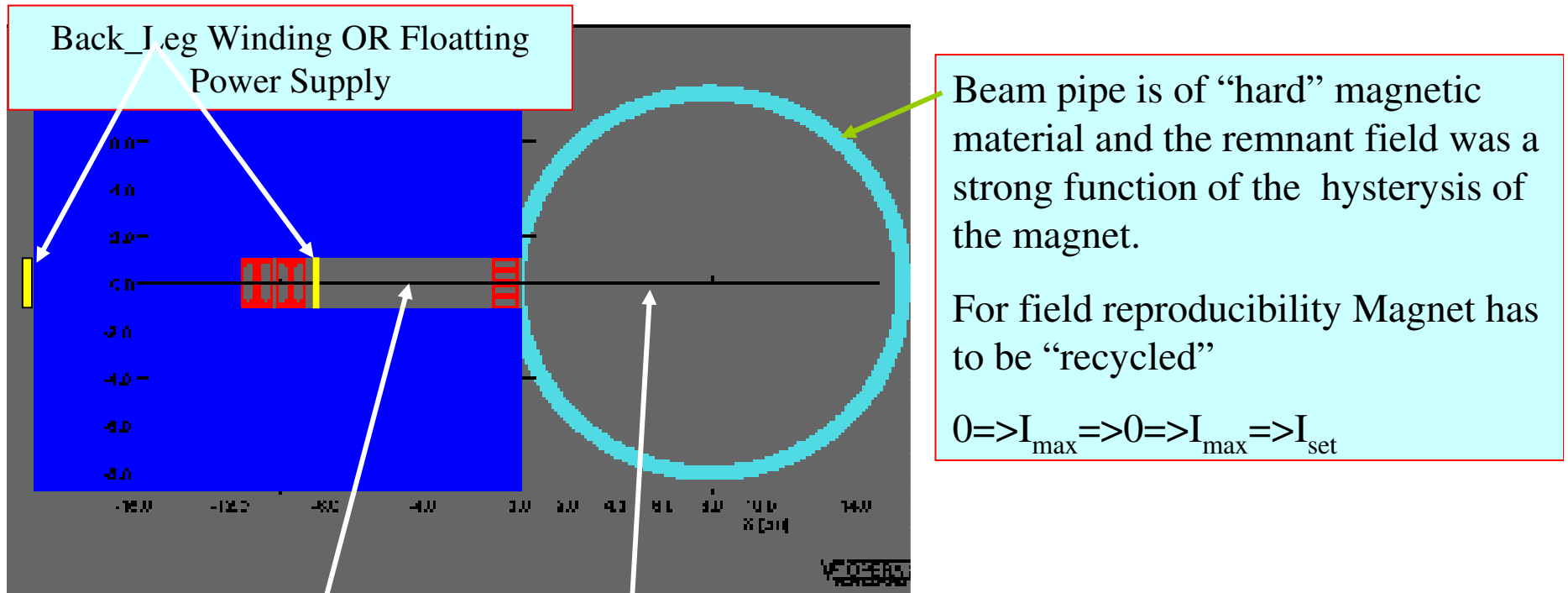
- Modes of Operation of the “D6 Current” Septum:
 - a) For a given magnet the Back_leg winding was powered at a given current to minimize the fringe field at the circulating beam region.
 - b) Lower the magnet current to zero, “slowly” , Back_Leg Winding was Powered to generate same field conditions for the circulating beam as a) above.
 - c) Set magnet current to zero, “fast” , Back_Leg Winding was Powered to generate same field conditions for the circulating beam as a) above.

No Magnetic field measurements were performed to measure the effect of the “D6 Septum” on the circulating beam under the different conditions of operation above. Therefore we had not information on the Back_leg Winding current_setting which minimizes the field strength at the circulating field region.

- Beam measurements at the different operation modes “D6 Current” Septum Showed:
 - The strength of fringe field generated by the septum after a “fast” shut off of the Septum was ~ 0.25 [mrad] on a 2.1 [T.m] rigid beam. This could NOT be corrected by the 0.1 [mrad] strong Back_leg winding.
 - The strength of fringe field generated by the septum was ~ 0.08 [mrad] on a 2.1 [T.m] rigid beam. This could be corrected by the Back_leg winding.

A procedure is adapted to maintain the “same field” at the fringe field region of the septum at three a) b) c) different operating conditions of the Septum

Three of the operation modes of the D6 Septum

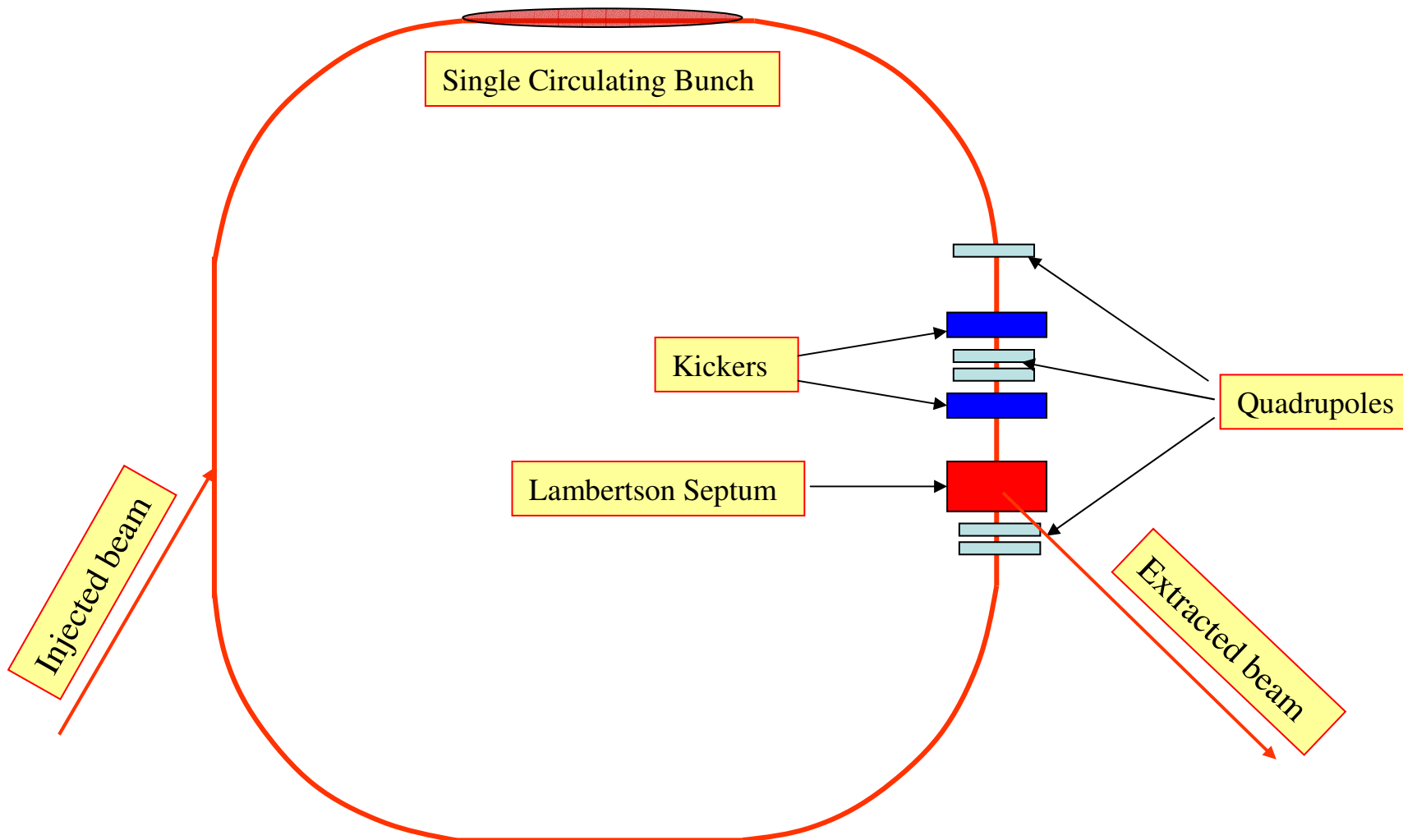


Mode	B_{circ}	I_{bkl}	B_{fringe}	
(a)	B_0 (NSRL)	$(I_{\text{bkl}})_0$	“Minimize” fringe Field	No magnetic field measurements performed in the fringe field region. $B_{\text{fringe}}(I_{\text{main_mag}})$
(b)	Set to 0 slowly from B_0 (RHIC)	$(I_{\text{bkl}})_1$	“Minimize” fringe Field	The beam pipe generated remnant fringe field equivalent to 0.8 mrad
(c)	Set to 0 fast from B_0 (NSRL Access)	$(I_{\text{bkl}})_2$	“Minimize” fringe Field	The beam pipe generated remnant fringe field equivalent to 2.5 mrad. Field of Back_leg had to be reversed then back to reduce the remnant field.

Recommendations to improve the operations of the NSRL “D6” “current Septum Magnet

- Measure Magnet:
 - Measure the B_{fringe} in the circulating beam region as a function of the current (I_{D6}) of the D6 magnet.
 - For a given (I_{D6}) measure the current I_{bkl} of the Back_leg winding for which the field in the circulating beam region is minimized.
- Modify Magnet:
 - Replace the magnetic pipe of the circulating beam region with one which is of very soft magnetic material, therefore of low remnant field.
 - Replace the magnetic pipe with a non-magnetic material, and use only the back leg winding to minimize the field in the circulating field region.

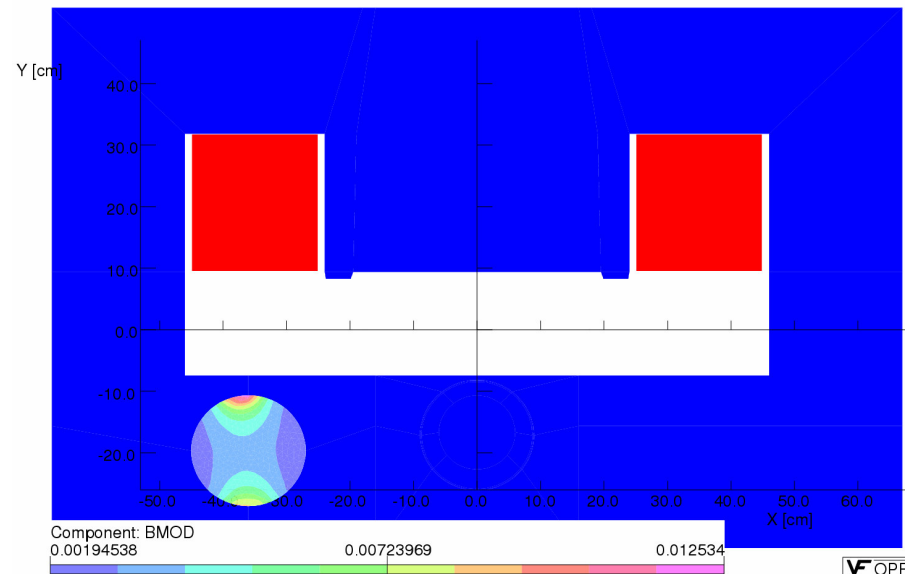
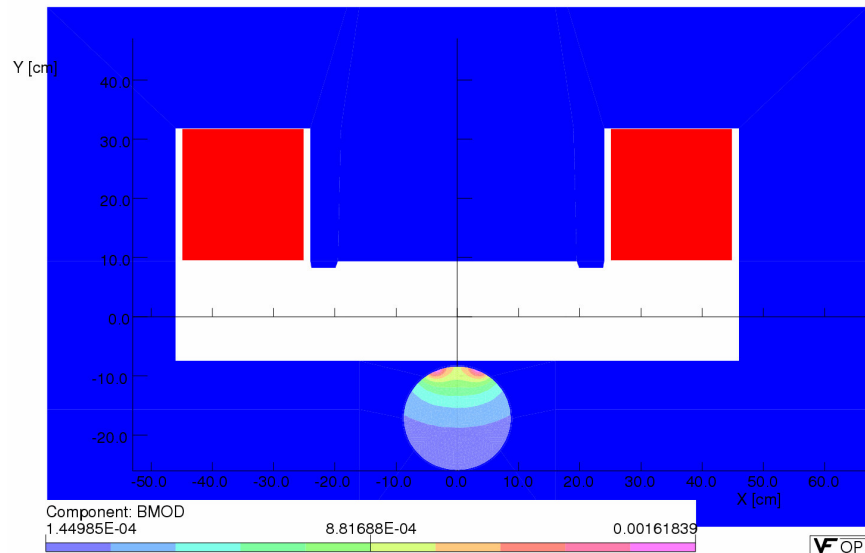
Schematic Diagram of the Extraction Region of the SNS Ring



Modeling the “Lambertson” Septum Magnet for the accumulator Ring of the Spallation_Neutron_Source (SNS)

Engineering Design: James Rank

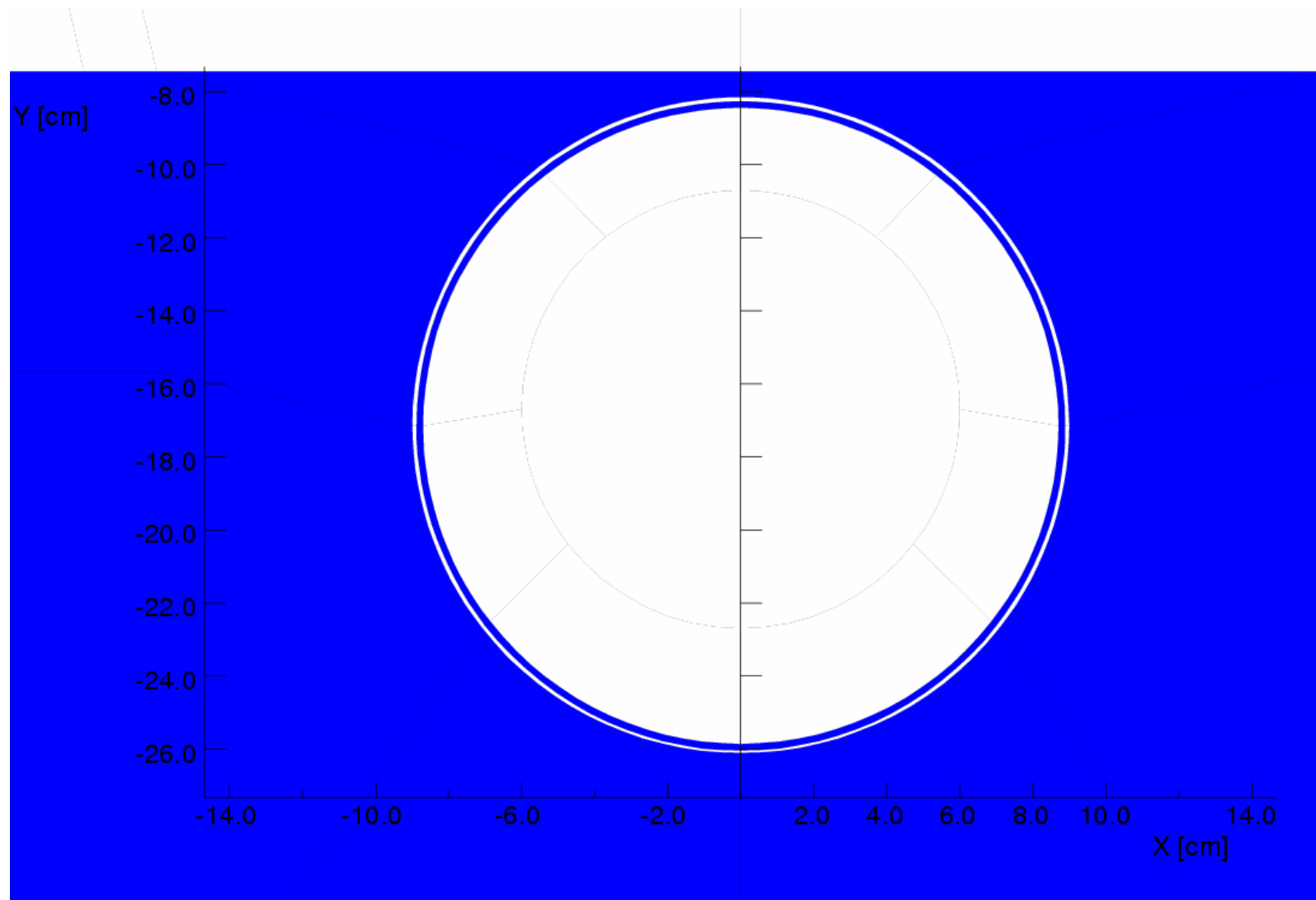
$$L_{\text{iron}}=2.24 \text{ [m]} \quad I_{\text{max}}=2.4 \text{ [kA]} \quad J_{\text{max}}=300 \text{ [A/cm}^2\text{]} \quad B_{\text{max}}=8.0 \text{ [kG]}$$



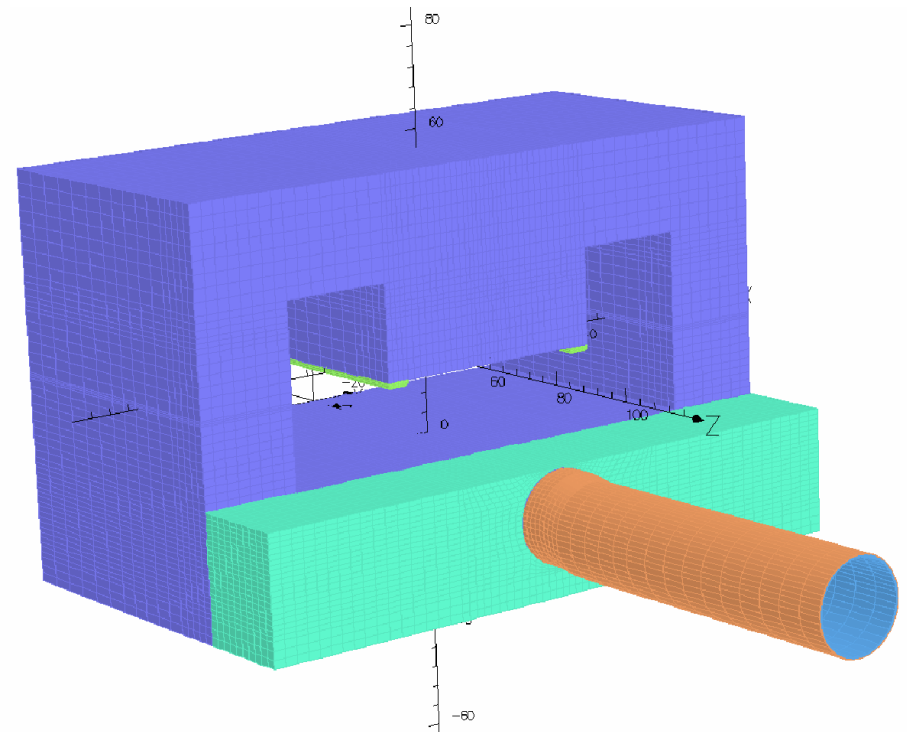
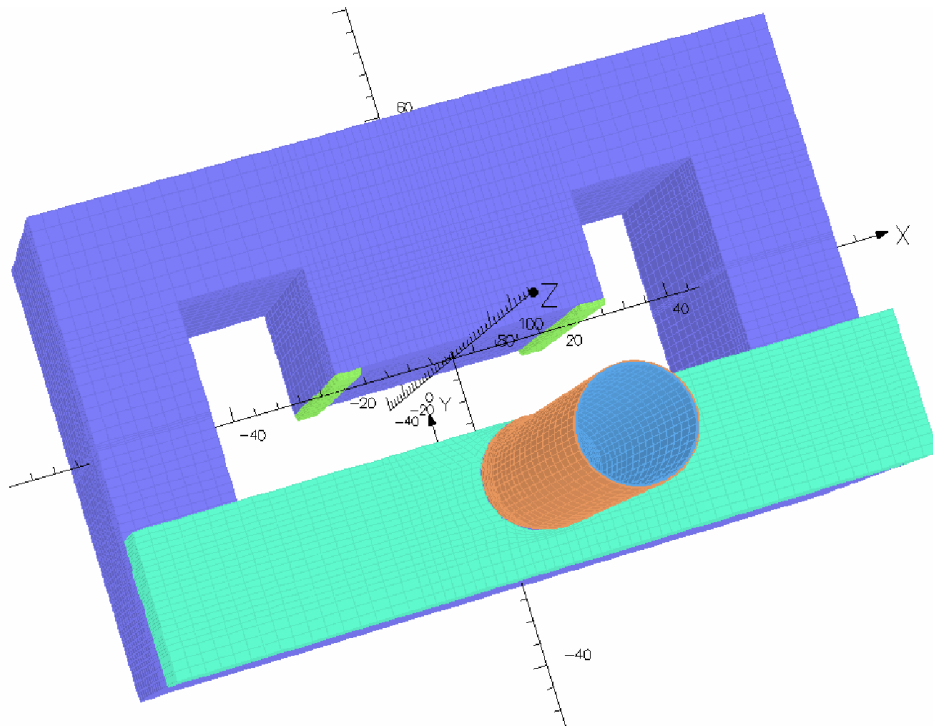
The 2D modelling is required to speed up:

- The optimization process of the main field of the magnet (Beam Extraction Region)
- The calculation of the amount of iron that will reduce regions of saturation in the magnet.
- The minimization process of the field in the circulating field region.

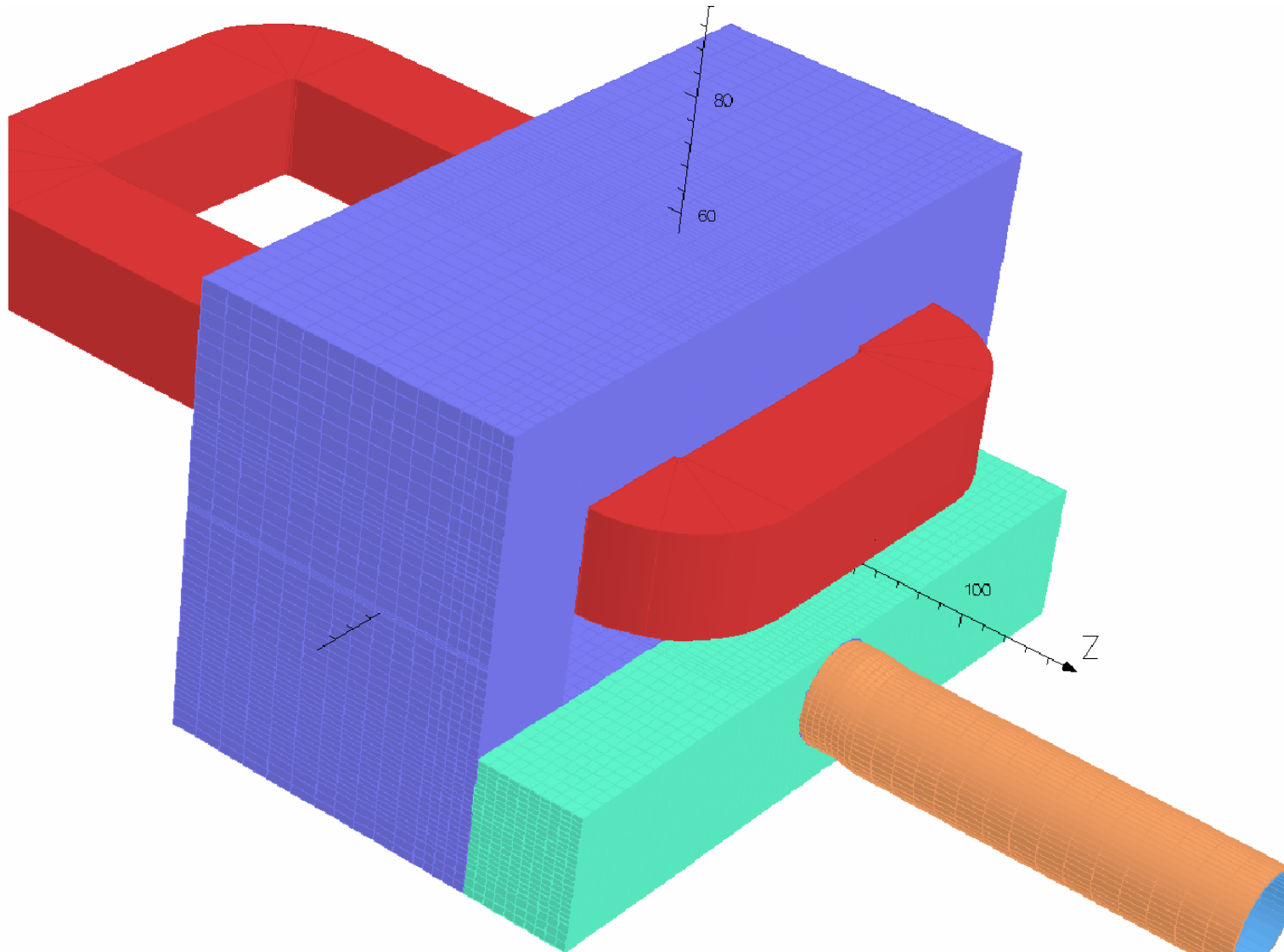
Cross Section of the Septum Region at the Entrance of the Septum magnet
Magnetic pipe is used to minimize the field strength in the Circ. Beam Region



Three Dimensional Model of the “Lambertson” Septum Magnet at the Entrance

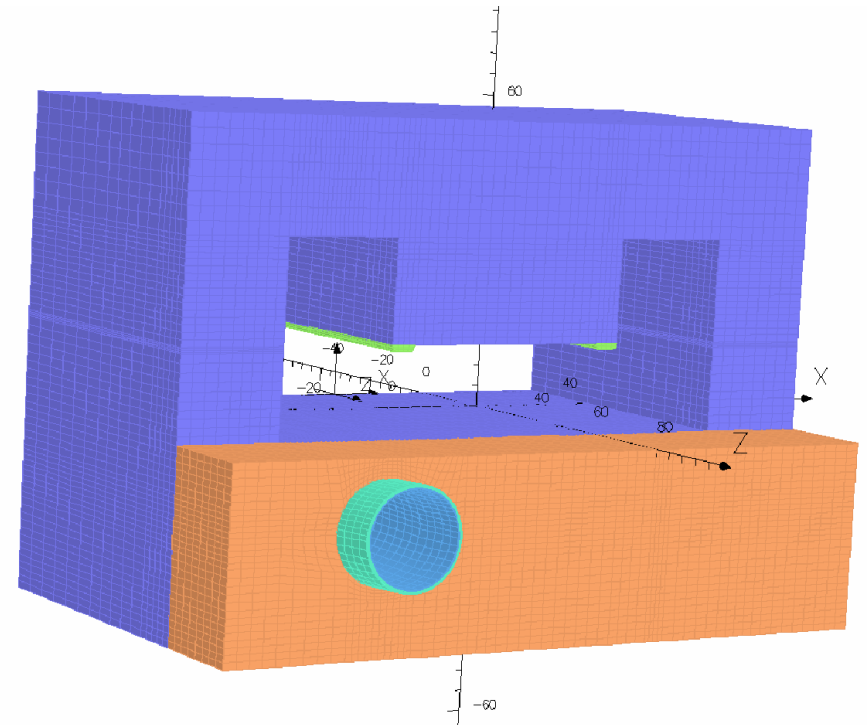
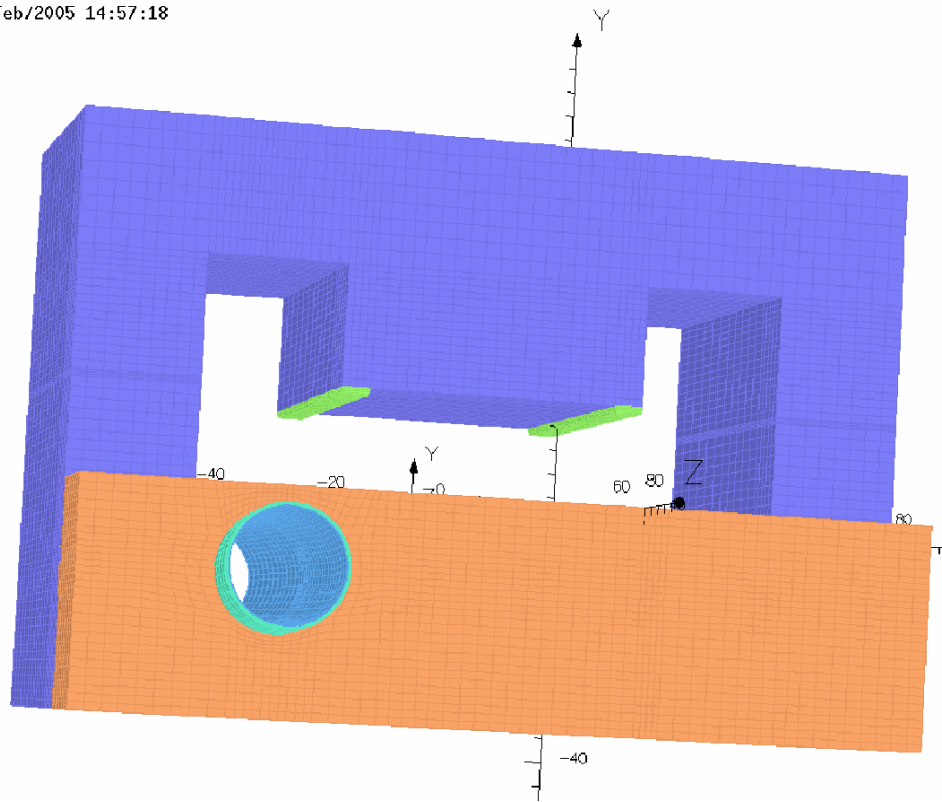


Model at the Entrance of the “Lambertson” Septum Magnet with the coil

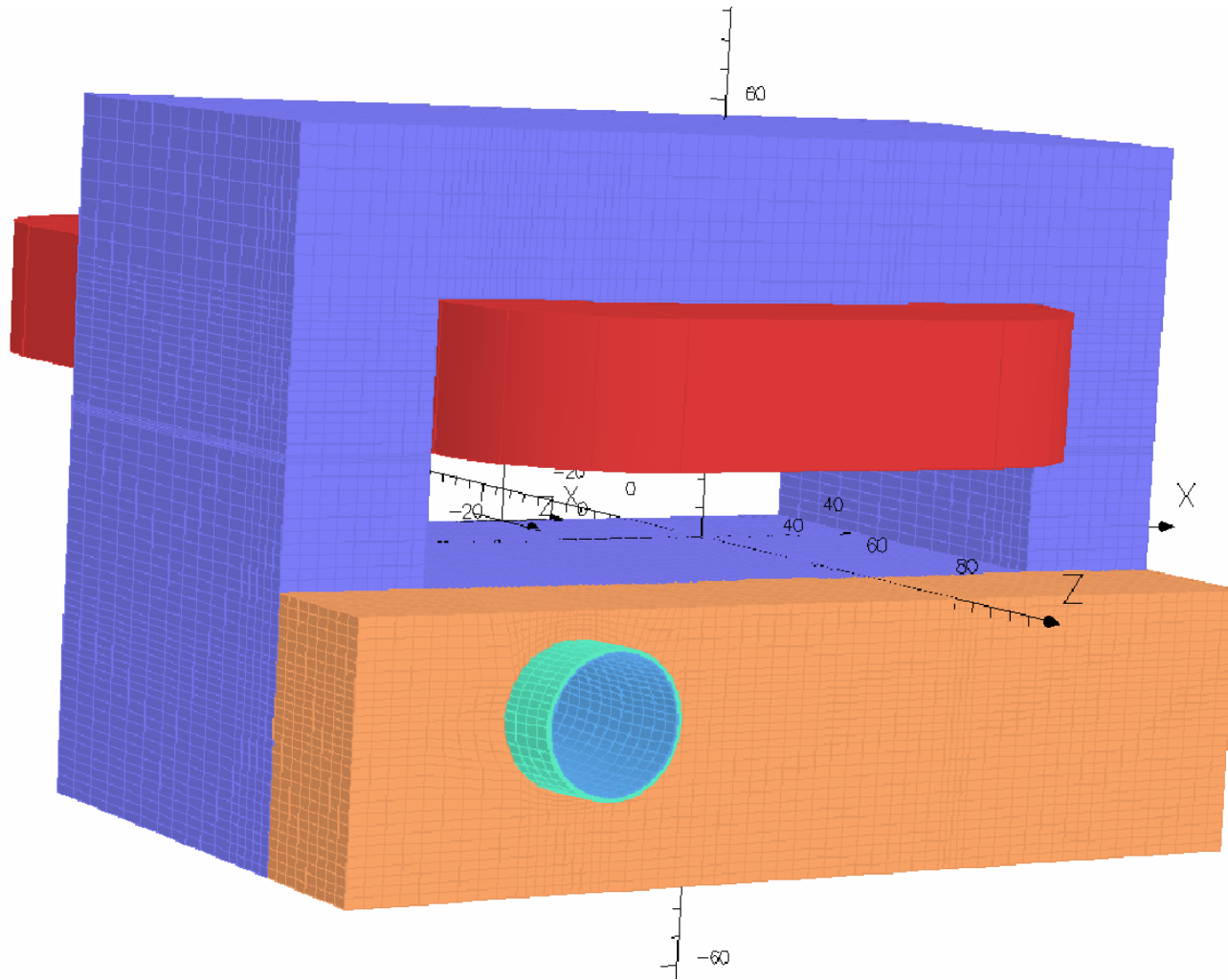


Three Dimensional Model of the “Lambertson” Septum Magnet at the Exit

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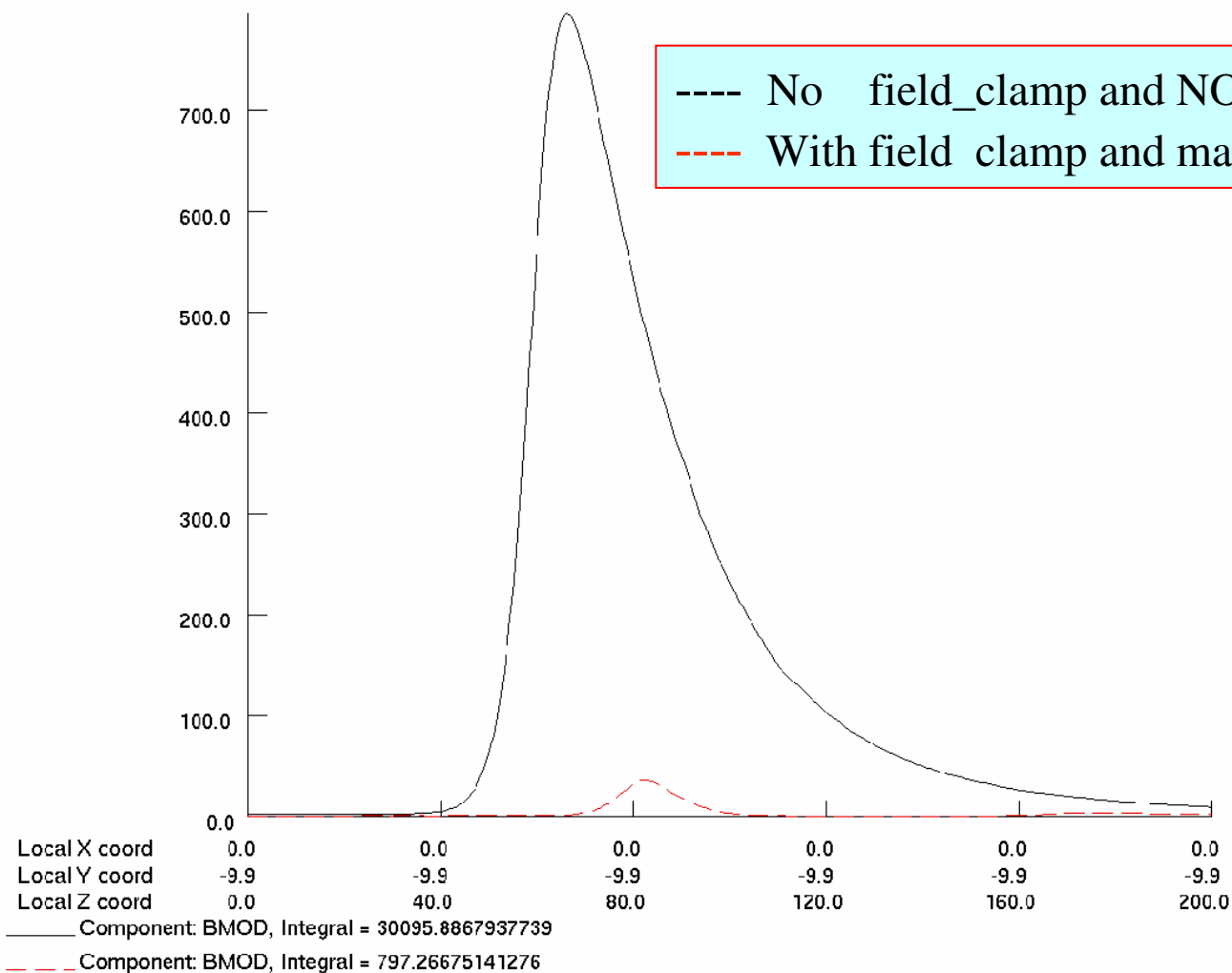


Model at the Exit of the “Lambertson” Septum Magnet with the coil



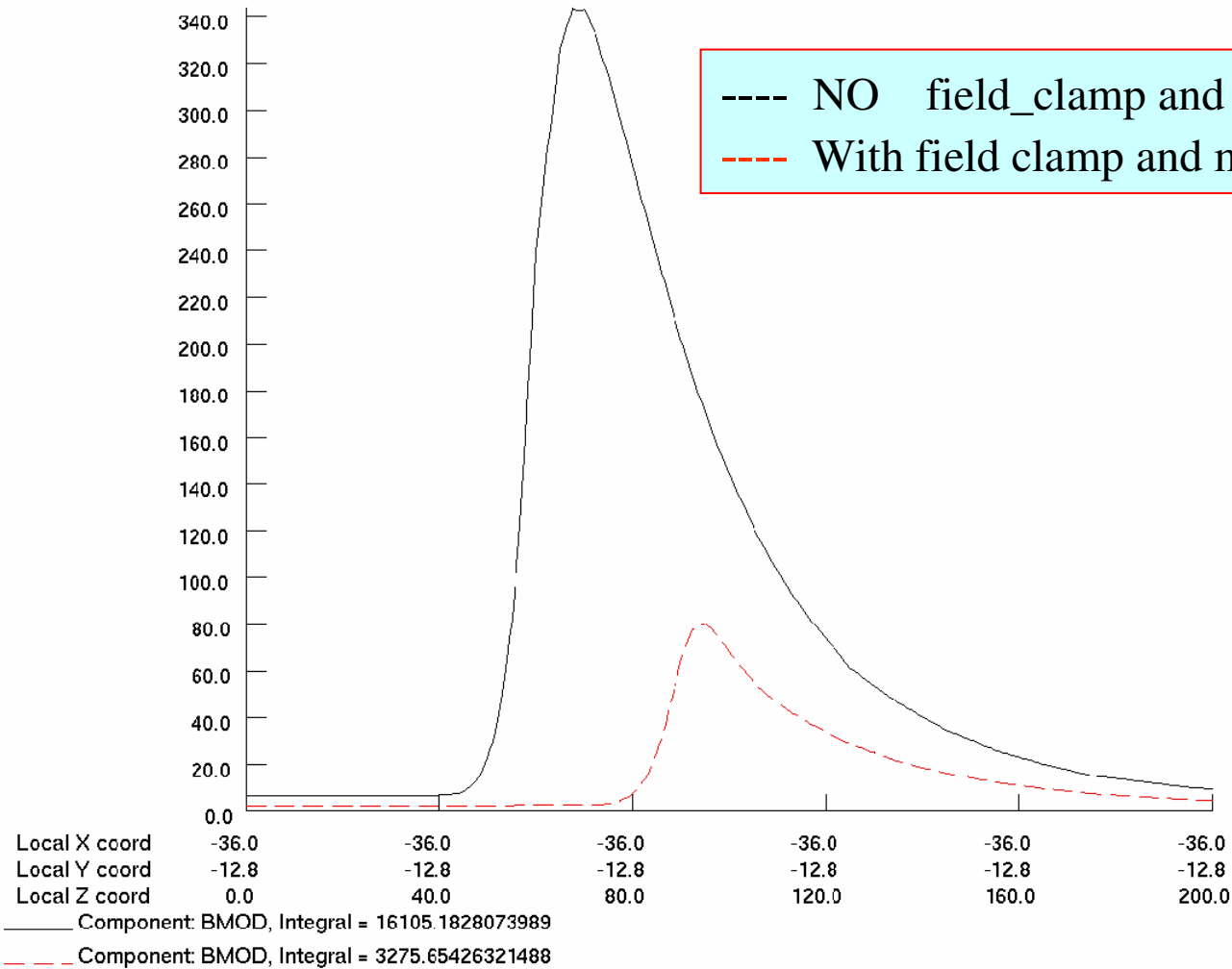
B_{mod} along the beam direction of the circulating beam at the Entrance of the 'Lambertson' magnet

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B_{mod} along the beam direction of the circulating beam at the Exit of the 'Lambertson' magnet

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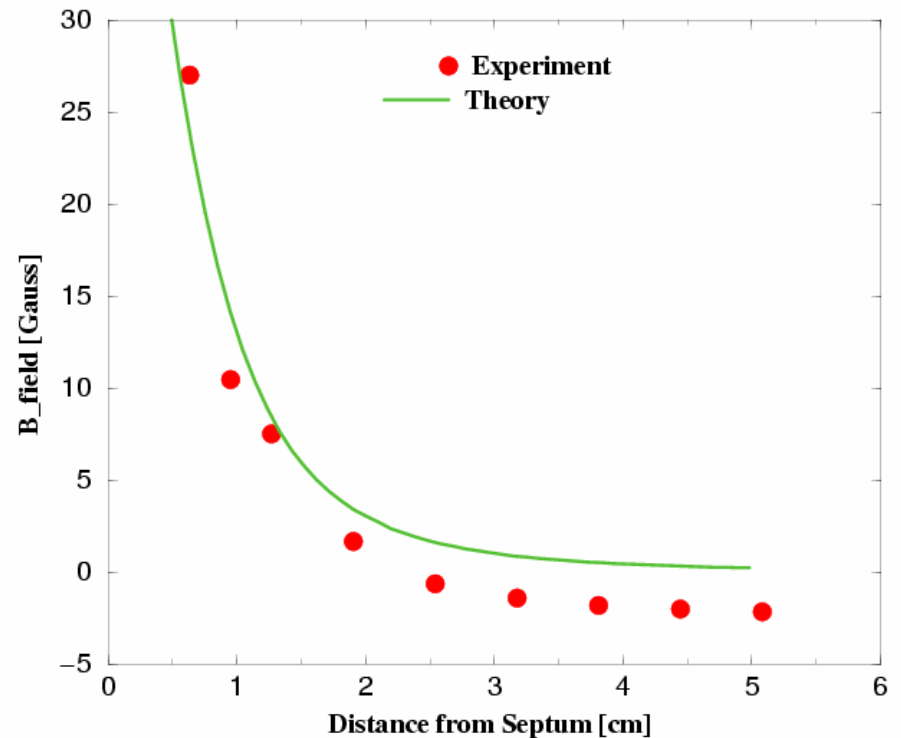
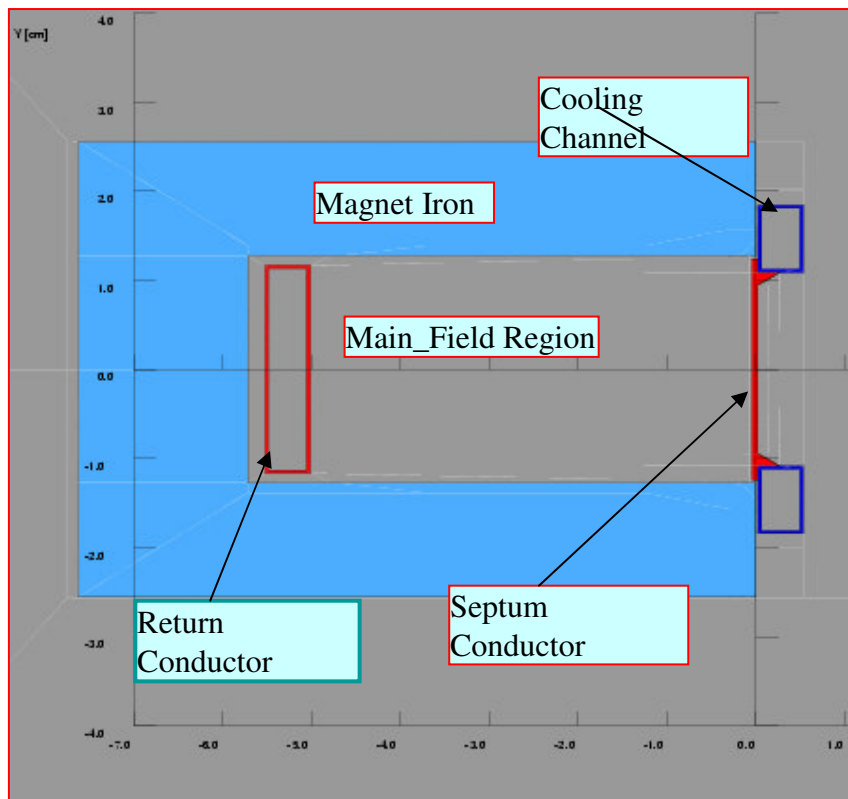


Magnet is in Building 902 Ready to for Magnetic field Measurements to be performed

We will see the magnet during the tour.

- Integral field Measurements ($\int B_y dz$) in the main field region to calculate the transfer function of the magnet
- Integral Harmonics Measurements at the circulating beam region (at $r=r_0$)
- $\int B_r(z,r)dz = \int B_{\text{dip}}(z,r)dz \sin(\theta) + \int B_{\text{quad}}(z,r)dz \sin(2\theta) + \int B_{\text{sex}}(z,r)dz \sin(3\theta) +$
..... $\int B_{12\text{pole}}(z,r) dz \cdot \sin(6\theta) + \dots \int B_{20\text{pole}}(z,r) dz \cdot \sin(10\theta) + \dots \int B_{28\text{pole}}(z,r) dz \cdot \sin(14\theta)$
..... $\int A_{\text{dip}}(z,r)dz \sin(\theta) + \int A_{\text{quad}}(z,r)dz \sin(2\theta) + \int A_{\text{sex}}(z,r)dz \sin(3\theta) +$
..... $\int A_{12\text{pole}}(z,r) dz \cdot \sin(6\theta) + \dots \int A_{20\text{pole}}(z,r) dz \cdot \sin(10\theta) + \dots \int A_{28\text{pole}}(z,r) dz \cdot \sin(14\theta)$

The F5 “Thin” current septum



- Recommendations for improvement:
 - Use techniques we learned from our colleagues from Japan
 - Use backleg winding
 - Use of a conducting magnetic material for a thin septum

Conclusions

- The performance from the operation of:
 - RHIC Injection “Lambertson” Septum Magnet
 - H10 Extraction “current” Septum Magnet

Showed good agreement with the calculations

- The performance from the operation of:
 - D6 “current” Septum Magnet

Showed that the “large” remnant field in the vacuum pipe in the circulating beam region is critical for the operation of the septum when low rigidity (<2 [T.m]) beams are circulating in the accelerator and the modes of the operation in the Booster vary.